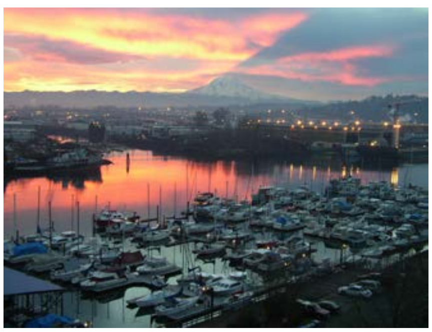
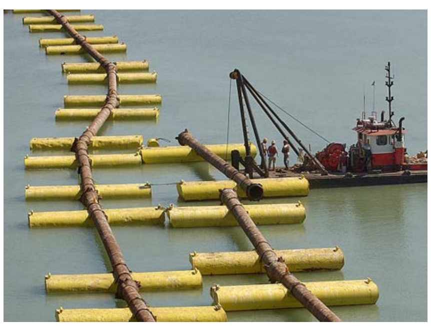
THEA FOSS AND WHEELER-OSGOOD WATERWAYS REMEDIATION PROJECT

YEAR 10 MONITORING

BENTHIC RECOLONIZATION MONITORING PRELIMINARY FINDINGS MEMORANDUM

AUGUST 11, 2016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PRELIMINARY FINDINGS MEMORANDUM
BENTHIC RECOLONIZATION MONITORING

INTRODUCTION

This memorandum presents the findings from Year 10 benthic recolonization monitoring performed in the Thea Foss and Wheeler-Osgood Waterways during July 2016.

Monitoring was performed to document and evaluate the success of the benthic recolonization. Benthic habitat was altered by historical contamination and the subsequent sediment dredging and capping actions completed in the waterways. Given improvements in the habitat resulting from the completed remedial actions, the waterway is expected to be recolonized by benthic infauna and epifauna common to Commencement Bay. The benthic recolonization monitoring was performed in accordance with the Operations, Maintenance, and Monitoring Plan (OMMP) for the Thea Foss and Wheeler-Osgood Waterways Remediation Project (City of Tacoma 2006).

The monitoring plan includes 17 locations within the remediation areas and four background locations in the area near the mouth of the waterway where no remedial action was required (Figure 1). The monitoring approach utilizes standard Sediment Profile Imaging (SPI) technology. SPI allows for data to be collected on sediment composition, benthic habitat classification, infaunal successional stages, redox potential discontinuity (RPD), and organism-sediment index (OSI).

In addition to the SPI survey, the monitoring plan includes collection of benthic grab samples at all benthic recolonization sampling locations. The benthic grab samples are preserved and archived for potential benthic community analysis, if necessary. In accordance with the OMMP, archived samples are to be analyzed only if SPI results are inconclusive or require verification.

Most of the benthic sampling locations are co-located with 0 to 10 cm chemical quality sampling locations established for performance monitoring. At these locations, chemical quality data are derived from the performance samples. Four locations are not co-located with a performance sample. At these locations, the monitoring plan requires collection and archiving of a sediment sample for potential future chemical analysis, if needed.

All sampling locations, sampling methods, and other protocols are described in detail in the OMMP for the Thea Foss and Wheeler-Osgood Waterways Remediation Project.

SUMMARY OF BENTHIC RECOLONIZATION MONITORING REQUIREMENTS

Sediment Profile Imaging

As part of benthic recolonization monitoring, the OMMP requires that SPI photographs be recorded at all benthic monitoring locations in the Thea Foss and Wheeler-Osgood Waterways. An SPI camera photographs the surface sediment profile up to a depth of approximately 20 cm at each benthic monitoring location. The photographs provide direct observation of the benthic organisms found at the monitoring locations, as well as the physical conditions of the biologically active sediment zone (upper 10 cm). The OMMP requires that three replicate SPI images be obtained and analyzed at each monitoring location. Taking three replicate images at each location allows for the characterization of any variability in habitat conditions that may exist on the spatial scale of a few meters between individual camera probes.

The parameters that are monitored using the SPI method allow for the comparison of measurements over time to evaluate benthic habitat conditions, characterize sediment types, map disturbance gradients if observed, and assess benthic habitat quality and recolonization. Parameters that are measured and evaluated using the SPI method include:

- Sediment Type Determination;
- Surface (Sediment-Water Interface) Boundary Roughness;
- Prism Penetration Depth;
- Apparent Redox Potential Discontinuity (RPD) Depth;
- Infaunal Successional Stages;
- Biological Mixing Depth; and
- Organism-Sediment Index (OSI).

Over the course of OMMP monitoring, the success of benthic recolonization is evaluated at each monitoring location relative to previous years of monitoring results at the same location based on the parameters measured using SPI. Intra-location qualitative comparisons are made to evaluate the quality of the benthic habitat in remediation areas. Background benthic monitoring results provide additional information on the benthic community in non-remediated areas.

Benthic Infaunal Monitoring Requirements

Collection of five replicate benthic infaunal grab samples for potential benthic community analysis is required at each benthic monitoring location. Sample collection is conducted in accordance with the Recommended Protocols for Sampling and Analyzing Subtidal Benthic Macroinvertebrate Assemblages in Puget Sound (Tetra Tech 1986). Samples are collected using a grab sampler or similar equipment capable of collecting samples that are relatively consistent in volume and penetration depth. Samples are then sieved and the collected benthic organisms preserved and archived for possible later analysis, if necessary, to provide additional information concerning benthic recolonization.

Co-Located Sediment Samples

Collection of a surface (0 to 10 cm) sediment sample during benthic infaunal grab sampling is required at the four benthic monitoring locations not co-located with sediment performance monitoring sample locations. The samples are archived for possible chemical analysis if determined to be necessary to provide additional information concerning benthic recolonization. If analysis is performed, chemical concentrations are compared to the Sediment Quality Objectives (SQOs).

SUMMARY OF FIELD ACTIVITIES AND OBSERVATIONS

Sediment Profile Imaging

SPI was conducted in the Thea Foss and Wheeler-Osgood Waterways on July 1, 2016. The SPI was conducted by INSPIRE Environmental, LLC (a Germano & Associates, Inc. partnership, the contractor who had conducted the previous OMMP SPI monitoring events) with additional support and equipment provided by Floyd|Snider and Research Support Services. Weather conditions were sunny and warm, with light breezes and calm water.

Twenty-one locations were successfully imaged, with four replicates per location. Four replicates were collected (although the OMMP requires only three replicates) to ensure that at least three high quality images were available for analysis. All sample locations remained consistent with the locations in the Year 7 monitoring effort, +/- 3 feet, with the exception of location BR-33. Location BR-33 was re-located between 6 and 10 feet from the Year 7 location because a large boat was docked in the immediate vicinity and the location was not accessible. SPI location coordinates and descriptions are shown in Table 1. A summary of the results from the SPI survey is provided below. The report presenting the complete results from evaluation of the SPI is provided in Attachment A. The complete set of SPI photographs is provided in Attachment B.

Benthic Infaunal Grab Sampling

Benthic infaunal grab sampling occurred July 11-14, 2016. Sampling was performed by a 7-person field crew made up of City of Tacoma (City), Floyd|Snider, and Washington Conservation Corps (WCC) personnel. Weather conditions each morning were cloudy and warm, then sunny with a gentle breeze in the afternoon and mostly calm water.

Sampling locations were determined using a GPS unit located on the davit used to deploy the grab sampler. Prior to the start of sampling each day the GPS unit was checked by taking readings at two benchmark locations established on the Center for Urban Waters dock. GPS readings for the benchmark locations for all three days were within +/- 12 feet for both northing and easting directions, just slightly above the OMMP target range of +/- 10 feet at the north benchmark location.

Benthic grab samples were collected at the Year 10 benthic monitoring locations, within less than 10 feet of where the SPI samples were taken on July 1, 2016. The boat was driven to the sample location using the location GPS coordinates. When the sampler was at the proper location, the boat driver signaled the winch operator and the sampler was deployed. Sampling was performed using a 0.189-square meter Van Veen grab sampler. The sampler was deployed five times at each location, from slightly offset positions, to capture five replicates per monitoring location.

Once collected, each sample was sieved through 1.0-mm and 0.5-mm nested sieves. After the sediment was gently washed away using water from the site, the material collected on each sieve was combined and placed in one or more sample containers, as necessary. A preservative solution of rose bengal in 10% formalin was added to each container; containers were inverted several times to ensure all organisms were exposed to the preservative.

Labels printed with the sample identification number, sample container number (if more than one container was required), and sample date were affixed to the outside of each container. An additional label on 100 percent rag paper was placed inside each container. After containers were sealed they were placed in coolers until transport to the City laboratory at the end of each field day. Chain of custody forms were initiated when each sample was taken. Benthic grab sample collection forms are provided in Attachment C.

The sediment in the background benthic sample locations (i.e., BR-02 through BR-05) was observed to primarily consist of silt with trace sand in BR-02 and BR-03, and slightly more sand in BR-04 and BR-05. The natural recovery area sample locations (i.e., BR-06, BR-07, BR-09, BR-10, and BR-11) were observed to primarily consist of silt with some sand and gravel. The dominant visible benthic infauna captured on the sieve screens for these nine samples were polychaetes, clams, worms, and brittle stars. A small crab was also captured in the sampler at one sample location (BR-03), and a hermit crab was observed in the sampler at sample location BR-10.

The sediment in the dredge to clean area benthic sample locations (i.e., BR-15, BR-21, BR-22, and BR-28) was observed to consist primarily of silt. The dominant visible benthic infauna captured on the sieve screens for these locations were polychaetes, clams, and worms. Small shrimp (approximately 2 cm or less) were also observed in BR-22 and BR-28.

At sample locations in the channel sand cap areas (i.e., BR-18, BR-23, BR-26, BR-29, and BR-31 through BR-33) and at the sample location within the enhanced natural recovery area (i.e., BR-16), sample material ranged from silt to gravel. The dominant visible benthic infauna captured on the sieve screens at these locations were clams, worms, and some small shrimp (approximately 2 cm or less).

At BR-18, larger infauna were captured including several large clams and three Dungeness crab (two live, one killed by the sampler). A BR-23, a small eel (approximately 10 cm) was captured. At BR-26, two Dungeness crab, one hermit crab, and one sea slug (approximately 4 cm) were captured. At BR-31, a snail (approximately 6 cm) and a juvenile geoduck were captured.

Overall, benthic infaunal density in the channel sand cap location BR-23 appeared to be lower than other locations in the waterway. Additionally, a hydrogen sulfide organic odor was noted at BR-23, and significant leafy and plastic debris.

Co-Located Sediment Sampling

On July 12-13, 2016, a sixth grab sample was collected at each of the four dredge to clean sample locations (i.e., BR-15, BR-21, BR-22, and BR-28). A 10-cm sediment sample was collected at each of these locations for potential chemical analysis because performance samples were not taken at these locations during the cap performance monitoring event. These samples will be archived for potential future analysis, if determined necessary based on benthic monitoring results. These sample collection forms are provided in Attachment D.

SUMMARY OF SPI BENTHIC RECOLONIZATION RESULTS

This section provides a summary of the results of the Year 10 SPI survey. The complete SPI survey report prepared by INSPIRE Environmental, LLC is provided in Attachment A. The complete set of SPI photographs is provided in Attachment B.

The SPI survey was performed to document and evaluate the success of the benthic recolonization. As stated above, parameters that are measured and evaluated using the SPI method include:

- Sediment Type Determination;
- Surface (Sediment-Water Interface) Boundary Roughness;
- Prism Penetration Depth;
- Apparent Redox Potential Discontinuity (RPD) Depth;
- Infaunal Successional Stages;
- Biological Mixing Depth; and
- Organism-Sediment Index (OSI).

A brief summary of the results for each of these parameters is provided below.

Sediment Type (Grain size)

The sediment throughout the Thea Foss and Wheeler-Osgood Waterways had a base of fine-grained silts and clays with the exception of two locations (BR-26 and BR-29) where the substrate was predominantly very fine sand. Eleven locations had a surface layer of silty, very fine to fine sand. In Year 2 and Year 4, distinct sedimentary layers from recent depositional events were visible in the profile images (e.g., in Year 4, the layers ranged from 3.9 to 8.2 cm in depth). In Year 10, however, as in the Year 7 survey, there were no distinct depositional intervals observed.

Of the six locations sampled where the channel sand cap material had been placed, only one showed any evidence of coarser sediments. The presence of the channel sand cap was noted at the surface and extending a few centimeters below the surface at location BR-31. This is in contrast to the previous monitoring in Year 2 where coarser sediments were not noted at the sediment surface at any monitoring location, but similar to the monitoring in Year 4 and Year 7, where coarser sediments were observed at two different locations: BR-32 and BR-33. These two locations are in the vicinity of BR-31 in the channel sand cap area further up the waterway near Johnny's Dock Marina. Overall, consistent with the Year 2, Year 4, and Year 7 monitoring, the sediment surface "seen" by biological receptors is essentially the same throughout the waterway (with the exception of location BR-31 in the channel sand cap area) due to natural depositional processes.

Surface Boundary Roughness

Surface boundary roughness was determined by measuring the vertical distance between the highest and lowest points of the sediment-water interface. The surface boundary roughness (sediment surface relief) typically ranges from 0.02 to 3.8 cm, and may be related to either physical structures (ripples, rip-up structures, mud clasts) or biogenic features (burrow openings, fecal mounds, foraging depressions). Biogenic roughness is related to the interaction of bottom turbulence and bioturbational activities.

Surface boundary roughness for each monitoring location ranged from 0.41 to 2.20 cm, with the majority of the roughness elements caused by biogenic processes. The overall average surface boundary roughness for the entire survey area was 1.13 cm. This average value is calculated using the location averages (which are the average of three replicates). The average surface boundary roughness values for each remedial area type for Year 2, Year 4, Year 7, and Year 10 are presented below for comparison:

Remedial Area	Year 2 Average Surface Boundary Roughness (cm)	Year 4 Average Surface Boundary Roughness (cm)	Year 7 Average Surface Boundary Roughness (cm)	Year 10 Average Surface Boundary Roughness (cm)
Background/No Action	1.07	0.75	0.90	1.02
Natural Recovery	0.91	0.88	0.73	0.83
Enhanced Natural Recovery	1.16	0.48	0.79	1.01
Dredge to Clean	1.00	1.22	0.98	1.32
Channel Sand Cap	1.59	1.16	1.10	1.33
Overall Waterway Average	1.17	1.05	0.93	1.13

Results for Year 10 were generally similar to Year 2, Year 4, and Year 7 monitoring, with increases observed from Year 10 in surface boundary roughness compared to Year 7 monitoring in all of the remedial areas.

Prism Penetration Depth

The range of average location prism penetration depths measured in the Thea Foss and Wheeler-Osgood Waterways was due to differences in relative sediment shear strength (from varying sediment grain-size major mode and range, depth of bioturbation, etc.) as well as differences in the camera settings (i.e., camera stop collar and weight settings) that were needed to get the necessary penetration of the SPI camera. Sediments at location BR-09 in the natural recovery area had the lowest shear strength, with one weight used at this location. The shallowest prism penetration depths were at three locations (BR-26, BR-29, and BR-31) in the channel sand cap remedial area.

The average overall prism penetration depth in the study area ranged from 5.34 to 17.69 cm. The overall site average camera prism depth was 13.26 cm, greater than the Year 2 and Year 7 averages of 11.38 and 12.32 cm respectively, but less than the Year 4 average of 13.48 cm. The average camera prism penetration depths for each remedial area type for Year 2, Year 4, Year 7, and Year 10 are presented below for comparison:

Remedial Area	Year 2 Average Camera Prism Penetration (cm)	Year 4 Average Camera Prism Penetration (cm)	Year 7 Average Camera Prism Penetration (cm)	Year 10 Average Camera Prism Penetration (cm)
Background/No Action	11.34	12.91	12.00	12.19
Natural Recovery	11.39	15.23	12.79	14.89
Enhanced Natural Recovery	9.50	13.40	12.18	14.79
Dredge to Clean	12.60	15.55	12.94	15.66
Channel Sand Cap	10.70	11.40	11.83	11.10
Overall Waterway Average	11.38	13.48	12.32	13.26

Results for Year 10 were generally greater than those found in Year 7 monitoring, with the exception of the channel sand cap area which was 0.73 cm lower.

Apparent Redox Potential Discontinuity Depth

The depth of the apparent Redox Potential Discontinuity (aRPD) in the sediment column is an important time-integrator of dissolved oxygen conditions within sediment porewaters. The depth is related to the supply rate of molecular oxygen by diffusion into the bottom and the consumption of that oxygen by the sediment and associated microflora. In the presence of bioturbating macrofauna, the thickness of the redox layer may be several centimeters. The apparent mean RPD depth can also be affected by local erosion.

The distribution of mean aRPD depths ranged from a low of 0.78 cm observed at BR-16 in the enhanced natural recovery area, to a high of 3.54 cm at BR-28, located in the dredge to clean remedial area. The overall location-averaged mean aRPD depth for the site was 1.43 cm. The average aRPD depths for each remedial area type for Year 2, Year 4, Year 7, and Year 10 are presented below for comparison:

Remedial Area	Year 2 Average aRPD Depth (cm)	Year 4 Average aRPD Depth (cm)	Year 7 Average aRPD Depth (cm)	Year 10 Average aRPD Depth (cm)
Background/No Action	2.77	2.49	2.98	1.59
Natural Recovery	2.50	2.38	1.85	1.04
Enhanced Natural Recovery	2.27	1.20	1.49	0.79

Dredge to Clean	2.20	2.43	1.92	2.45
Channel Sand Cap	1.78	1.69	1.41	1.11
Overall Waterway Area	2.26	2.13	1.91	1.43

Some of the lowest values (less than 1.0 cm; which can indicate stress or disturbance) were found at BR-07, BR-11 and BR-16 near the Foss Waterway Marina, BR-09 in the channel between the Foss Waterway Marina and Totem Marine, and BR-21 in the channel near the mouth of the Wheeler-Osgood Waterway. All of these locations had aRPD depths between 0.73 and 1.10 cm. These locations are different than the locations found in Year 7 to have aRPD depths of less than 1.0 cm, which included BR-10, BR-22, and BR-33.

Of the three locations in Year 7 with aRPD depths less than 1.0 cm, BR-22 showed marked improvement in Year 10 with a mean location aRPD of 3.15 cm, while BR-10 and BR-33 remained essentially the same.

Sulfur-reducing bacterial colonies (*Beggiatoa* spp.) were not observed at any locations in Year 10. These white, filamentous bacterial colonies appear at the sediment surface when oxygen concentrations in the benthic boundary layer are hypoxic. In past surveys, *Beggiatoa* was observed at BR-23. Conditions have therefore improved at this location, with no observed *Beggiatoa*, an increased aRPD, and Stage 3 fauna present in all images (discussed below).

Infaunal Successional Stage

Infaunal successional stages are recognized in SPI images by the presence of dense assemblages of near-surface polychaetes and/or the presence of subsurface feeding voids; both may be present in the same image. Mapping of successional stages is based on the theory that organism-sediment interactions in fine-grained sediments follow a predictable sequence after a major seafloor disturbance. This continuum of change in animal communities after a disturbance (primary succession) has been divided into three stages: Stage 1 is the initial community of tiny, densely populated polychaete assemblages; Stage 2 is the start of the transition to head-down deposit feeders; and Stage 3 is the mature, equilibrium community of deep-dwelling, head-down deposit feeders.

Ninety percent of all images (57 of 63 images) taken as part of Year 10 benthic recolonization monitoring, regardless of remedial area type, have evidence of Stage 3 infaunal taxa present, similar to the results of the Year 2, Year 4, and Year 7 surveys. Many locations were Stage 1 on 3 with small tube-building and burrowing fauna in the upper 1 to 2 cm of the sediment column and larger burrowing infauna at depth. For example, tubes of the surface-deposit feeder *Spiochaetopterus costarum* were seen at BR-26, BR-31, and BR-33 indicating Stage 2 or Stage 2→Stage 3 successional stages. Improvements in benthic community status were seen in the waterways overall—several locations that showed Stage 1→2 or Stage 2→3 in Year 7 now show Stage 3 taxa.

In the no action area at the mouth of the waterway where SPI sampling was performed at four background locations, and the natural recovery area where SPI sampling was performed at five locations, the infaunal successional stages ranged from Stage 2→3 to Stage 2 on 3 in all replicates, indicating no obvious signs of disturbance. This was an improvement in benthic community status from Year 7 when two of these locations, BR-05 (no action) and BR-07 (natural recovery), showed Stage 1→2 assemblages, with no Stage 3 taxa present.

The images from the enhanced natural recovery area showed extensive burrowing activities at depth, and the dredge to clean areas all had Stage 3 taxa present. Finally, successional assemblages found in the channel sand cap areas ranged from Stage 2→3 to Stage 2 on 3, with the exceptions of BR-29 and BR-31 that showed successional Stage 2 for all replicates, whereas in Year 7 Stage 3 taxa were present. Stage 1 or Stage 1→2 assemblages were not observed at any sampling locations, an improvement from Year 7 when two locations (BR-18 and BR-33) showed Stage 1 and Stage 1→2 assemblages.

Based on the Year 10 infaunal community analysis monitoring results, all of the remedial areas sampled show evidence of mature infaunal communities present and continue to show benthic ecosystem recovery.

Biological Mixing Depth

The depth to which sediments are bioturbated, or the biological mixing depth, can be an important parameter for studying either nutrient or contaminant flux in sediments. While the aRPD is one potential measure of biological mixing depth, it is quite common in profile images to see evidence of biological activity (burrows, voids, or actual animals) well below the mean aRPD.

Evidence of burrowing infauna and deposit feeding activity was present at the majority of locations surveyed in Year 10, similar to Year 7. Feeding voids were observed in about three-quarters of the images analyzed, which is an increase from Year 7, in which feeding voids were only observed in one-third of the images analyzed. The maximum bioturbation depths observed in the Thea Foss and Wheeler Osgood Waterways monitoring locations ranged from 4.95 cm at BR-29 (due to shallow prism penetration) to 18.25 cm at BR-06. The average biological mixing depth across all of the locations was 12.77 cm, with some relatively large infaunal deposit-feeding organisms present. The average biological mixing depth increased slightly from 12.55 cm in Year 7. The maximum depth of bioturbation for each remedial area type for Year 2, Year 4, and Year 7 are presented below for comparison:

Remedial Area	Year 2 Maximum Bioturbation Depth (cm)	Year 4 Maximum Bioturbation Depth (cm)	Year 7 Maximum Bioturbation Depth (cm)	Year 10 Maximum Bioturbation Depth (cm)
Background/No Action	13.57	13.43	13.23	13.06
Natural Recovery	14.88	16.33	14.56	18.25
Enhanced Natural Recovery	10.02	13.54	13.14	15.04
Dredge to Clean	18.15	17.66	15.59	16.89
Channel Sand Cap	18.86	15.26	20.05	15.69
Overall Waterway Average	12.26	12.71	12.55	12.77

Maximum results for Year 10 were generally similar to Year 2, Year 4, and Year 7, with some depth increase in the natural recovery, enhanced natural recovery, and dredge to clean areas and a decrease in the channel sand cap area depth, which is now similar to the Year 4 value.

Organism-Sediment Index

The Organism-Sediment Index (OSI) is a summary mapping statistic that is calculated on the basis of four independently measured SPI parameters: apparent mean RPD depth, presence of methane gas, low/no dissolved oxygen at the sediment-water interface, and infaunal successional stage.

The Year 10 overall median OSI for the entire study area is +7, compared to an overall median OSI of +8 in all three of the prior surveys. OSI values range from a median for the three replicates of +5 (BR-29 and BR-31) to a maximum value of +10 (BR-28). An OSI of +6 or less typically indicates that a benthic habitat has experienced physical disturbances, eutrophication, or excessive bioavailable contamination in the recent past.

Of the 21 locations sampled, five had a median location value less than +7 (BR-18, BR-26, BR-29, BR-31, and BR-33), an increase over the Year 7 previous survey where only one of the locations had a median location value less than +7 (BR-33). These locations are all within the channel sand cap area. Although in Year 10 BR-18 had an OSI value of +6 compared to +8 in Year 7, its OSI value has been variable over time and does not appear to be trending downward. BR-26, BR-29, and BR-31 do show decreasing OSI values between Year 2 and Year 10 sampling. BR-33 has consistently had an OSI value of +6 in all monitoring events.

In Year 7, it was noted that the OSI value of BR-23 decreased significantly between Year 2 and Year 4, from +7 to -3, but then improved to an OSI value of +7. In Year 10, BR-23 has maintained the median OSI value of +7.

The lowest OSI value of 0 was measured in one replicate of BR-16. The other two replicates had OSI values of +7 however. This low value was due to more advanced signs of organically-enriched sediments and the presence of methane bubbles observed in the replicate with an OSI value of 0. However, other parameters used to assess benthic health such as aRPD and successional stage are not significantly different between the replicates. All three replicates show signs of a relatively high sediment oxygen demand with darker reduced sediment below the aRPD.

The median OSI values for each remedial area type for Year 2, Year 4, Year 7, and Year 10 are presented below for comparison:

Remedial Area	Year 2 Median OSI Value	Year 4 Median OSI Value	Year 7 Median OSI Value	Year 10 Median OSI Value
Background/No Action	+8	+9	+9	+8
Natural Recovery	+8	+8	+8	+7
Enhanced Natural Recovery	+9	+7	+7	+7
Dredge to Clean	+9	+9	+8	+8.5
Channel Sand Cap	+7.5	+8	+7	+6
Overall Waterway Average	+8	+8	+8	+7

The median OSI values for all remedial areas are greater than +6 with the exception of the channel sand cap area.

SUMMARY OF PRELIMINARY FINDINGS

The primary objectives of the SPI survey were to document the physical nature of the benthic habitat and observable organism-sediment interactions at the sediment-water interface to evaluate benthic recolonization in the Thea Foss and Wheeler-Osgood Waterways. The following summarizes the preliminary findings from the Year 10 SPI survey:

- While the benthic habitat classification were similar for the entire area in Year 2, there were observed differences in sediment type at certain locations in Year 4 and Year 7. For example, BR-18 showed evidence of the surface layer being eroded (most likely from propwash effects). However, this pattern was not observed in Year 10. Instead, the primary difference in sediment types in Year 10 was the observation of very fine to fine sand and no silt/clay in the profile images for BR-26 and BR-29.

- All of the remedial areas sampled show evidence of mature infaunal communities present and evidence of benthic ecosystem recovery. There was observed stability in the habitat conditions at monitoring BR-23, adjacent to a City outfall, where a positive change in the habitat conditions from Year 4 to Year 7 (from an OSI of -3 to an OSI of +7) had previously been observed.
- Consistent with the Year 7 SPI survey, there were no indications of quantum sediment input that formed distinct depositional layers.
- In Year 7, conditions improved noticeably from Year 4, with BR-33 being the only location that continued to show retrograde successional conditions and high sediment oxygen demand. In Year 10, this location had improved to a Stage 2→3 community.
- While the results from Year 2 indicated that the completed remedial actions had a positive effect on benthic habitat quality, the Year 4 results indicated there were degraded conditions at three locations in particular (BR-18, BR-23, and BR-33). The Year 7 results showed improved benthic habitat quality at all locations with the exception of BR-33, described above. Although the Year 10 survey showed evidence of organic loading and high sediment oxygen demand (locations with aRPDs < 1 cm), the benthic communities present appear to be able to balance these demands and persist in all remediation areas in the Thea Foss and Wheeler-Osgood Waterways, as indicated by the continued presence of mature infaunal communities with Stage 3 taxa and a waterway average OSI of +7.
- No further action is warranted based on the results of benthic recolonization monitoring performed in Year 10. Because SPI results do not require verification, analysis of the archived sediment and benthic samples does not appear warranted. If additional benthic recolonization monitoring is deemed a necessary part of the long-term monitoring, it may be appropriate to focus only on areas of organic loading and disturbance and conducted using consistent methods and quantitative indices for long-term evaluation.

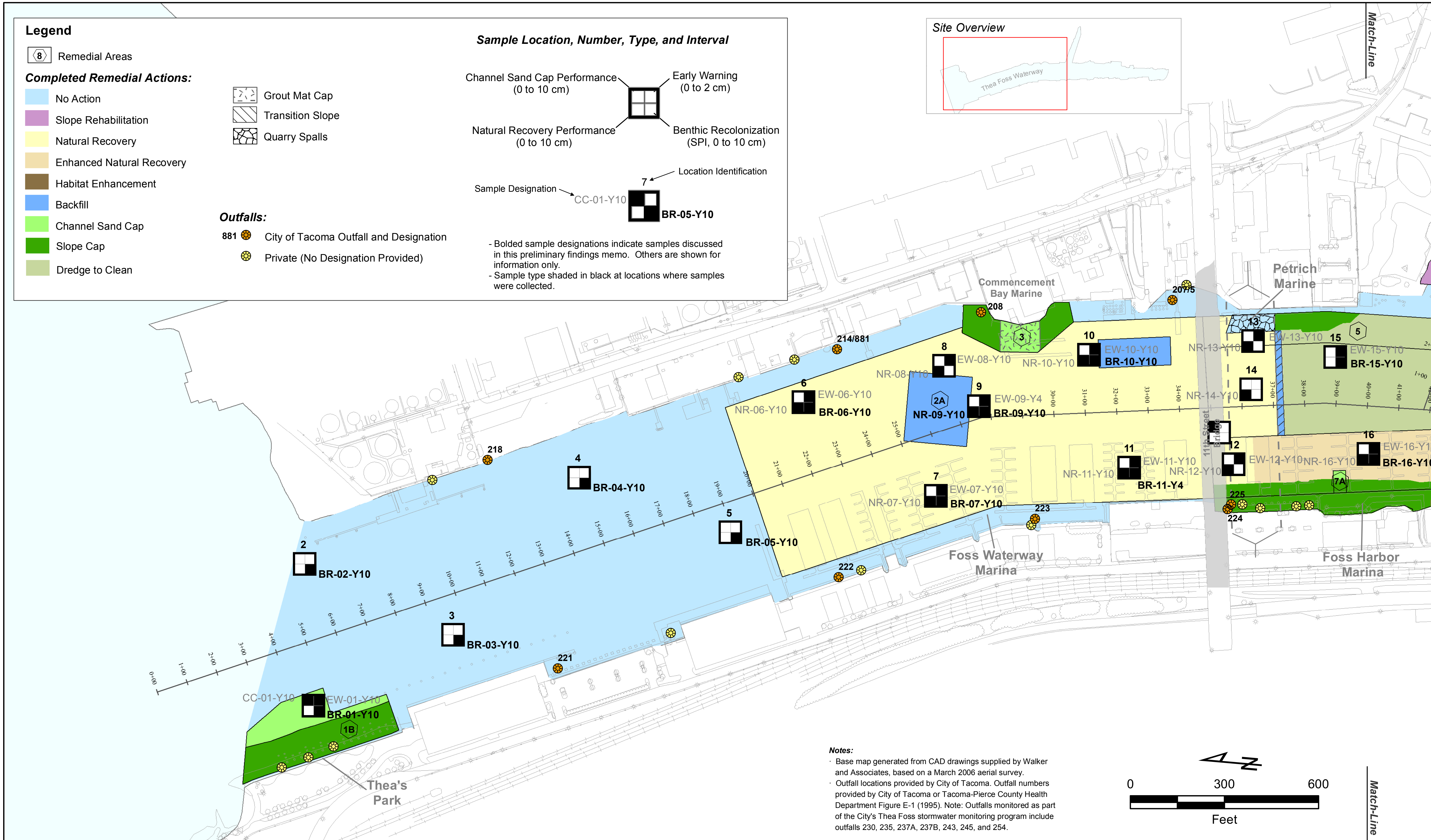
TABLES

FIGURES

ATTACHMENTS

Table 1 Summary of Monitoring Locations for SPI, Benthic Infaunal Grab Samples, and Co-Located Sediment Samples

Benthic Sample Location	Background or Remedial Action	Easting	Northing	SPI	Benthic Infaunal Grab	Co-Located Sediment
BR-02	Background	1159549.794	709117.19	7/1/2016	7/11/2016	
BR-03	Background	1159367.000	708623.602	7/1/2016	7/11/2016	
BR-04	Background	1159896.997	708306.498	7/1/2016	7/11/2016	
BR-05	Background	1159767.003	707772.601	7/1/2016	7/11/2016	
BR-06	Natural Recovery	1160202.995	707569.302	7/1/2016	7/11/2016	
BR-07	Natural Recovery	1159944.002	707129.702	7/1/2016	7/12/2016	
BR-09	Natural Recovery	1160238.002	707011.002	7/1/2016	7/12/2016	
BR-10	Natural Recovery	1160429.996	706682.002	7/1/2016	7/12/2016	
BR-11	Natural Recovery	1160088.007	706518.098	7/1/2016	7/12/2016	
BR-15	Dredge to Clean	1160493.997	705900.102	7/1/2016	7/12/2016	7/12/2016
BR-16	Enhanced Natural Recovery	1160194.005	705765.500	7/1/2016	7/12/2016	
BR-18	Cap	1161211.999	705365.598	7/1/2016	7/12/2016	
BR-21	Dredge to Clean	1160395.998	705284.199	7/1/2016	7/13/2016	7/13/2016
BR-22	Dredge to Clean	1160586.006	704864.102	7/1/2016	7/13/2016	7/13/2016
BR-23	Cap	1160266.001	704790.799	7/1/2016	7/13/2016	
BR-26	Cap	1160556.997	704276.899	7/1/2016	7/13/2016	
BR-28	Dredge to Clean	1160731.001	703745.699	7/1/2016	7/13/2016	7/13/2016
BR-29	Cap	1160404.002	703652.298	7/1/2016	7/13/2016	
BR-31	Cap	1160737.002	703157.702	7/1/2016	7/14/2016	
BR-32	Cap	1160458.002	703022.702	7/1/2016	7/14/2016	
BR-33	Cap	1160576.999	702827.201	7/1/2016	7/14/2016	



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Thea Foss and Wheeler-Osgood Waterways OMMP

Figure 1 (Page 1 of 2)
Benthic Recolonization Monitoring Locations

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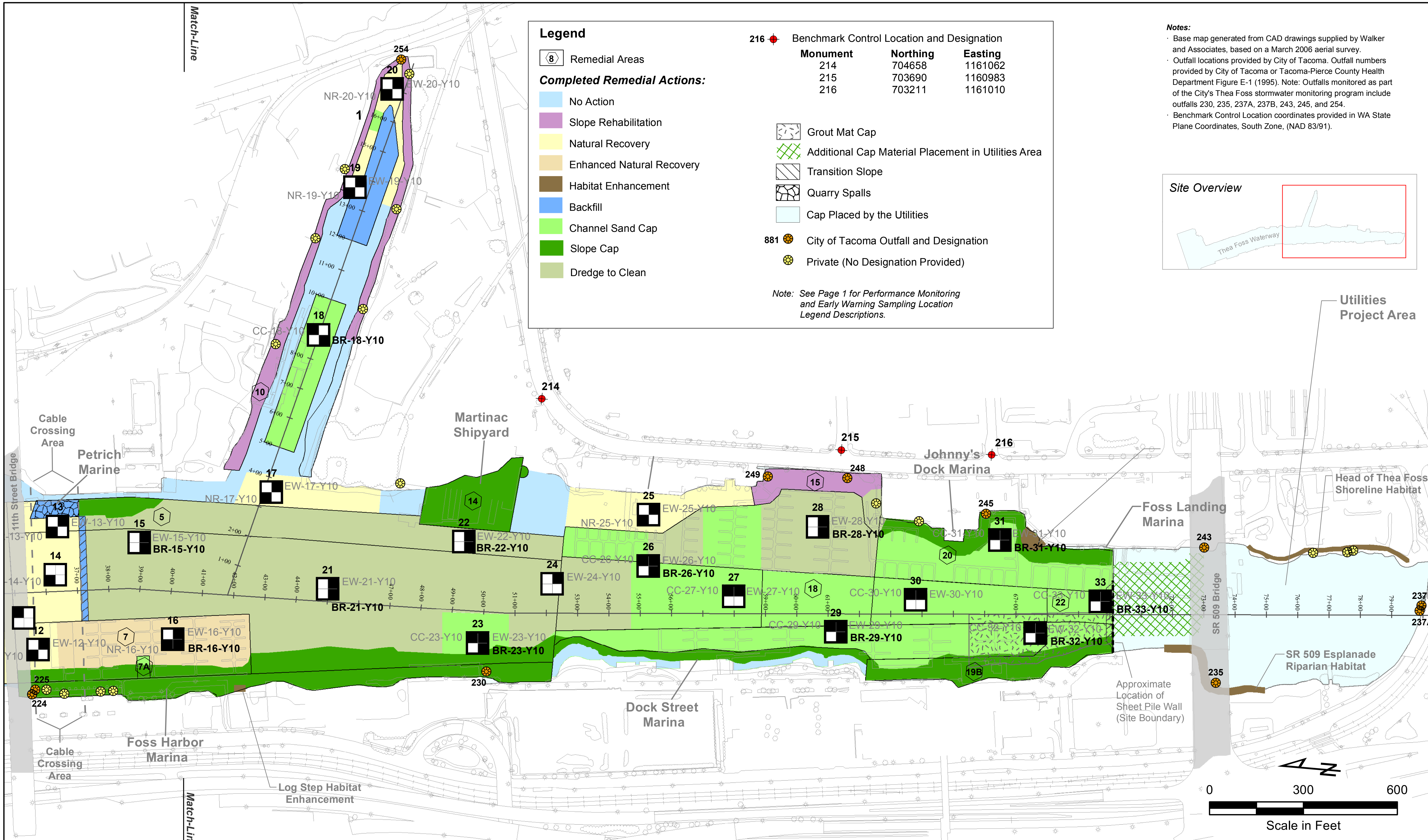
Date: 8/1/2016



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Thea Foss and Wheeler-Osgood Waterways
OMMP

Figure 1 (Page 2 of 2)
Benthic Recolonization Monitoring Locations

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Date: 8/1/2016

ATTACHMENT A

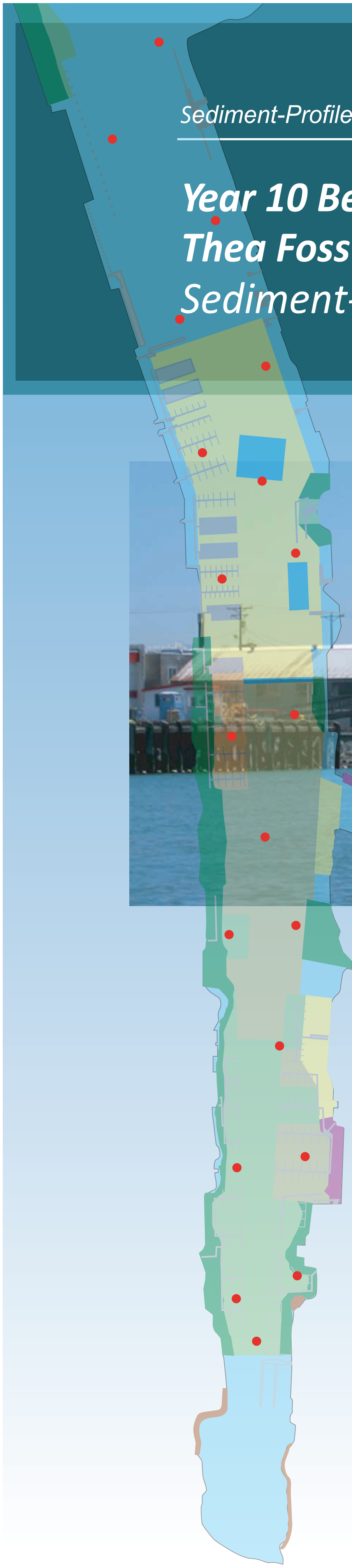
Year 10 Benthic Recolonization Monitoring of the Thea Foss and Wheeler-Osgood Waterways: Sediment Profile Imaging Survey

Sediment-Profile Imaging Report

July 2016

Year 10 Benthic Recolonization Monitoring of the Thea Foss and Wheeler-Osgood Waterways:

Sediment-Profile Imaging Survey / July 2016



Prepared for:

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Sediment-Profile Imaging Report

Year 10 Benthic Recolonization Monitoring of the Thea Foss and Wheeler-Osgood Waterways: Sediment-Profile Imaging Survey/ July 2016

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July 2016

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1.0 INTRODUCTION

In accordance with the Operations, Maintenance, and Monitoring Plan (OMMP) for the Thea Foss and Wheeler-Osgood Waterways Remediation Project, a sediment profile imaging (SPI) survey was carried out in the Thea Foss and Wheeler-Osgood Waterways (Figure 1-1) by INSPIRE Environmental, LLC (formerly Germano & Associates, Inc. (G&A)) at a series of pre-determined stations on July 1, 2016. The purpose of the SPI survey was to document and evaluate the success of benthic recolonization in the Thea Foss and Wheeler-Osgood Waterways ten years following completion of remedial actions. The SPI data provide a valuable time-series record of information on many critical benthic habitat parameters, including sediment composition, benthic habitat classification, infaunal successional stages, apparent redox potential discontinuity (aRPD) and the organism-sediment index (OSI). Because the exact same locations were sampled this July as the three surveys carried out in 2008, 2010, and 2013, we are able to compare results among remedial areas to assess the rate of and any changes in benthic recolonization patterns.

2.0 MATERIALS AND METHODS

On July 1, 2016, scientists from INSPIRE collected sediment profile images at a total of 21 stations under the direction of Floyd|Snider, Inc. with vessel support from Eric Parker of Research Support Services, Bainbridge Island, WA. Acquisition of high-resolution sediment-profile images was accomplished using a Nikon D7100 digital single-lens reflex (SLR) camera with a 24.1-megapixel image sensor mounted inside an Ocean Imaging Model 3731 pressure housing system. Camera settings were f8, ISO 640, and 1/320 shutter speed. A total of 63 sediment profile images were selected for analysis (3 replicate images from each of 21 stations; see Figure 2-1) following field operations.

The same five different remedial areas that were sampled in 2008, 2010, and 2013 within the Thea Foss and Wheeler–Osgood Waterways were once again sampled during the SPI survey of July 2016; the remedial areas sampled were (Figure 2-1):

Remedial Area (# of Stations)	SPI Sampling Stations
Background/No Action (4)	BR02, BR03, BR04, BR05
Natural Recovery (5)	BR06, BR07, BR09, BR10, BR11
Enhanced Natural Recovery (1)	BR16
Dredge to Clean (4)	BR15, BR21, BR22, BR28
Channel Sand Cap (7)	BR18, BR23, BR 26, BR29, BR31, BR32, BR33

SPI was developed more than three decades ago as a rapid reconnaissance tool for characterizing physical, chemical, and biological seafloor processes and has been used in numerous seafloor surveys throughout North and South America, Asia, Europe, Antarctica, and Africa (Rhoads and Germano 1982, 1986, 1990; Revelas et al. 1987; Diaz and Schaffner 1988; Valente et al. 1992; Diaz 2004; Germano et al. 2011; Shumchenia et al. 2016). An Ocean Imaging Systems Model 3731 sediment-profile camera was used for this survey. A Nikon D7100 24-megapixel SLR camera with two 32-gigabyte secure digital (SD) memory cards is mounted horizontally inside a watertight housing on top of a wedge-shaped prism. The prism has a Plexiglas® faceplate at the front with a mirror placed at a 45° angle at the back. The camera lens looks down at the mirror, which reflects the image from the faceplate. The prism has an internal strobe mounted inside at the back of the wedge to provide illumination for the image; this chamber is filled with distilled water, so the camera always has an optically clear path. This wedge assembly is mounted on a moveable carriage within a stainless steel frame. The frame is lowered to the seafloor on a winch wire, and the tension on the wire keeps the prism in its "up" position. When the frame comes to rest on the seafloor, the winch wire goes slack and the camera prism descends into the sediment at a slow, controlled rate by the dampening action of a hydraulic piston so as not to disturb the sediment-water interface. On the way down, it trips a trigger that activates a time-delay circuit of variable length (operator-selected) to allow the camera to penetrate the seafloor before any image is taken (Figure 2-2). The knife-sharp edge of the prism transects the sediment, and the prism penetrates the bottom. The strobe is discharged after an appropriate time delay to obtain a cross-sectional image of the upper 20 cm of the sediment column. The resulting images give the viewer the same perspective as looking through the side of an aquarium half-filled with sediment. After the first image is obtained at the first location, the camera is then raised up about 2 to 3 meters off the bottom to allow the strobe to recharge; a wiper blade mounted on the frame removes any mud adhering to the faceplate. The strobe recharges within 5 seconds, and the camera is ready to be lowered again for a replicate image. Surveys can be accomplished rapidly by "pogo-sticking" the camera across an area of seafloor while recording positional fixes on the surface vessel.

Two types of adjustments to the SPI system are typically made in the field: physical adjustments to the chassis stop collars or adding/subtracting lead weights to the chassis to control penetration in harder or softer sediments, and electronic software adjustments to the Nikon D7100 to control camera settings. Camera settings (f-stop, shutter speed, ISO equivalents, digital file format, color balance, etc.) are selectable through a water-tight USB port on the camera housing and Nikon Control Pro® software. At the beginning of the survey, the time on the sediment-profile camera's internal data logger was synchronized with the internal clock on the computerized navigation system to local time. Details of the camera settings for each digital image are available in the associated parameters file embedded in the electronic image file; for this survey, the ISO-equivalent was set at 640. The additional camera settings used were as follows: shutter speed was 1/250, f9, white balance set to flash, color mode to Adobe RGB, sharpening to none, noise reduction off, and storage in compressed raw Nikon Electronic Format (NEF) files (approximately 30 MB each).

Four replicate images were taken at each station; the three replicates with the best quality images from each station were then chosen for analysis. Coordinates for these are provided in Appendix A. For presentation purposes, the position of the first of the three replicates is plotted on all figures. Each SPI replicate is identified by the time recorded on the digital image file in the camera and on disk along with vessel position on the navigation computer. The unique time stamp on the digital image was then cross-checked with the time stamp in the navigational system's computer data file. The field crew kept redundant written sample logs. Images were downloaded periodically (sometimes after each station) to verify successful sample acquisition or to assess what type of sediment/depositional layer was present at a particular station. Digital image files were re-named with the appropriate station name immediately after downloading on deck as a further quality assurance step.

Test exposures of the Kodak® Color Separation Guide (Publication No. Q-13) were made on deck at the beginning of the survey to verify that all internal electronic systems were working to design specifications and to provide both a scale and color standard against which final images could be checked for proper color balance. A spare camera and charged battery were carried in the field at all times to ensure uninterrupted sample acquisition. After deployment of the camera at each station, the frame counter was checked to make sure that the requisite number of replicates were taken. In addition, a prism penetration depth indicator on the camera frame was checked to verify that the optical prism had actually penetrated the bottom to a sufficient depth. Changes in prism weight amounts, the presence or absence of mud doors, and chassis stop positions were recorded for each replicate image. Images were inspected at high magnification to allow the chief scientist to determine whether or not additional sampling stations were needed to delineate the habitat gradients as well as to determine whether any stations needed resampling with different stop collar or weight settings.

Following completion of the field operations, the raw image files were color calibrated in Adobe Camera Raw® by synchronizing the raw color profiles to a KODAK® Color Separation Guide that was photographed on-site with the SPI camera. The raw images were then converted to high-resolution Photoshop Document (PSD) format files using the minimal amount of image file compression, maintaining an Adobe RGB (1998) color profile. The PSD images were then calibrated and analyzed in Adobe Photoshop®. Calibration information was determined by measuring 1-cm gradations from the Kodak® Color Separation Guide. This calibration information was applied to all SPI images analyzed. Linear and area measurements were recorded as number of pixels and converted to scientific units using the calibration information.

Measured parameters were recorded on a Microsoft Excel© spreadsheet. INSPIRE scientist Marisa Guarinello subsequently checked these data as an independent quality assurance/quality control review of the measurements before final interpretation was performed. Spatial distributions of SPI parameters from stations within the study area were mapped using ArcGIS.

2.1. MEASURING, INTERPRETING, AND MAPPING SPI PARAMETERS

2.1.1. Sediment Type

The sediment grain-size major mode and range were visually estimated from the color images by overlaying a grain-size comparator that was at the same scale. This comparator was prepared by photographing a series of Udden-Wentworth size classes (equal to or less than coarse silt up to granule and larger sizes) with the SPI camera. Seven grain-size classes were on this comparator: >4 ϕ (silt-clay), 4-3 ϕ (very fine sand), 3-2 ϕ (fine sand), 2-1 ϕ (medium sand), 1-0 ϕ (coarse sand), 0 – (-1) ϕ (very coarse sand), < -1 ϕ (granule and larger). The lower limit of optical resolution of the photographic system was about 62 microns, allowing recognition of grain sizes equal to or greater than coarse silt ($\geq$ 4 ϕ). The accuracy of this method has been documented by comparing SPI estimates with grain-size statistics determined from laboratory sieve analyses (Germano et al. 2011).

The comparison of the SPI images with Udden-Wentworth sediment standards photographed through the SPI optical system was also used to map near-surface stratigraphy such as sand-over-mud and mud-over-sand. When mapped on a local scale, this stratigraphy can provide information on relative transport magnitude and frequency.

2.1.2. Prism Penetration Depth

The SPI prism penetration depth was measured from the bottom of the image to the sediment-water interface. The area of the entire cross-sectional sedimentary portion of the image was digitized; this number was divided by the calibrated linear width of the image to determine the average penetration depth. Linear maximum and minimum depths of penetration were also measured. All three measurements (maximum, minimum, and average penetration depths) were recorded in the data file.

Prism penetration is a noteworthy parameter; if the number of weights used in the camera is held constant throughout a survey, the camera functions as a static-load penetrometer. Comparative penetration values from sites of similar grain size give an indication of the relative water content of the sediment. Highly bioturbated sediments and rapidly accumulating sediments tend to have the highest water contents and greatest prism penetration depths.

The depth of penetration also reflects the bearing capacity and shear strength of the sediments. Over consolidated or relic sediments and shell-bearing sands resist camera penetration. Highly bioturbated, sulfidic, or methanogenic muds are the least consolidated, and deep penetration is typical. Seasonal changes in camera prism penetration have been observed at the same station in other studies and are related to the control of sediment geotechnical properties by bioturbation (Rhoads and Boyer 1982). The effect of water temperature on bioturbation rates appears to be important in controlling both biogenic surface relief and prism penetration depth (Rhoads and Germano 1982).

2.1.3. Small-Scale Surface Boundary Roughness

Surface boundary roughness was determined by measuring the vertical distance between the highest and lowest points of the sediment-water interface. The surface boundary roughness (sediment surface relief) measured over the width of sediment profile images typically ranges from 0.02 to 3.8 cm, and may be related to either physical structures (ripples, rip-up structures, mud clasts) or biogenic features (burrow openings, fecal mounds, foraging depressions). Biogenic roughness typically changes seasonally and is related to the interaction of bottom turbulence and bioturbational activities.

The camera must be level in order to take accurate boundary roughness measurements. In sandy sediments, boundary roughness can be a measure of sand wave height. On silt-clay bottoms, boundary roughness values often reflect biogenic features such as fecal mounds or surface burrows. The size and scale of boundary roughness values can have dramatic effects on both sediment erodibility and localized oxygen penetration into the bottom (Huettel et al., 1996).

2.1.4. Thickness of Depositional Layers

Because of the camera's unique design, SPI can be used to detect the thickness of depositional and dredged material layers. SPI is effective in measuring layers ranging in thickness from 1 mm to 20 cm (the height of the SPI optical window). During image analysis, the thickness of newly deposited sedimentary layers can be determined by measuring the distance between the pre- and post-disposal sediment-water interface. Recently deposited material is usually evident because of its unique optical reflectance and/or color relative to the underlying material representing the pre-disposal surface. Also, in most cases, the point of contact between the two layers is clearly visible as a textural change in sediment composition, facilitating measurement of the thickness of the newly deposited layer.

2.1.5. Mud Clasts

When fine-grained, cohesive sediments are disturbed, either by physical bottom scour or faunal activity, e.g., decapod foraging, intact clumps of sediment are often scattered about the seafloor. These mud clasts can be seen at the sediment-water interface in SPI images. During analysis, the number of clasts was counted and their oxidation state assessed. The abundance, distribution, oxidation state, and angularity of mud clasts can be used to make inferences about the recent pattern of seafloor disturbance in an area.

Depending on their place of origin and the depth of disturbance of the sediment column, mud clasts can be reduced or oxidized. In SPI images, the oxidation state is apparent from the reflectance. Also, once at the sediment-water interface, these mud clasts are subject to bottom-water oxygen concentrations and currents. Evidence from laboratory microcosm observations of reduced sediments placed within an aerobic environment indicates that oxidation of reduced surface layers by diffusion alone is quite rapid, occurring within 6 to 12 hours (Germano 1983). Consequently, the detection of reduced mud clasts in an obviously aerobic setting suggests a recent origin. The size and shape of the mud clasts are also revealing; some clasts seen in the profile images are artifacts caused by the camera deployment (mud clots falling off the back of the prism or the wiper blade). Naturally-occurring mud clasts may be moved and broken by bottom currents and animals (macro- or meiofauna; Germano 1983). Over time, these naturally-occurring, large angular clasts become small and rounded.

2.1.6. Apparent Redox Potential Discontinuity Depth

Aerobic near-surface marine sediments typically have higher reflectance relative to underlying hypoxic or anoxic sediments. Surface sands washed free of mud also have higher optical reflectance than underlying muddy sands. These differences in optical reflectance are readily apparent in SPI images; the oxidized surface sediment contains particles coated with ferric hydroxide (an olive or tan color when associated with particles), while reduced and muddy sediments below this oxygenated layer are darker, generally gray to black (Fenchel 1969; Lyle 1983). The boundary between the colored ferric hydroxide surface sediment and underlying gray to black sediment is called the apparent redox potential discontinuity (aRPD).

The depth of the aRPD in the sediment column is an important time-integrator of dissolved oxygen conditions within sediment porewaters. In the absence of bioturbating organisms, this high reflectance layer (in muds) will typically reach a thickness of 2 mm below the sediment-water interface (Rhoads 1974). This depth is related to the supply rate of molecular oxygen by diffusion into the bottom and the consumption of that oxygen by the sediment and associated microflora. In sediments that have very high sediment oxygen demand (SOD), the sediment may lack a high reflectance layer even when the overlying water column is aerobic.

In the presence of bioturbating macrofauna, the thickness of the high reflectance layer may be several centimeters. The relationship between the thickness of this high reflectance layer and the presence or absence of free molecular oxygen in the associated porewaters must be considered with caution. The actual RPD is the boundary or horizon that separates the positive Eh region of the sediment column from the underlying negative Eh region. The exact location of this Eh = 0 boundary can be determined accurately only with microelectrodes; hence, the relationship between the change in optical reflectance, as imaged with the SPI camera, and the actual RPD can be determined only by making the appropriate *in situ* Eh measurements. For this reason, the optical reflectance boundary, as imaged, is described in this study as the "apparent" RPD and it was mapped as a mean value. In general, the depth of the actual Eh = 0 horizon will be either equal to or slightly shallower than the depth of the optical reflectance boundary (Rosenberg et al. 2001). This is because bioturbating organisms can mix ferric hydroxide-coated particles downward into the bottom below the Eh = 0 horizon. As a result, the mean aRPD depth can be used as an estimate of the depth of porewater exchange, usually through porewater irrigation (bioturbation). Biogenic particle mixing depths can be estimated by measuring the maximum and minimum depths of imaged feeding voids in the sediment column. This parameter represents the particle mixing depths of head-down feeders, mainly polychaetes.

The rate of depression of the aRPD within the sediment is relatively slow in organic-rich muds, on the order of 200 to 300 micrometers per day; therefore, this parameter has a long time constant (Germano and Rhoads 1984). The rebound in the aRPD is also slow (Germano 1983). Measurable changes in the aRPD depth using the SPI optical technique can be detected over periods of 1 or 2 months. This parameter is used effectively to document changes (or gradients) that develop over a seasonal or yearly cycle related to water temperature effects on bioturbation rates, seasonal hypoxia, SOD, and infaunal recruitment. Time-series aRPD measurements following a disturbance can be a critical diagnostic element in monitoring the degree of recolonization in an area by the ambient benthos (Rhoads and Germano 1986).

The mean aRPD depth also can be affected by local erosion. Scouring can wash away fines and shell or gravel lag deposits, and can result in a very thin surface oxidized layer. During storm periods, erosion may completely remove any evidence of the aRPD (Fredette et al. 1988).

Another important characteristic of the aRPD is the contrast in reflectance at this boundary. This contrast is related to the interactions among the degree of organic loading, the bioturbation activity in the sediment, and the concentrations of bottom-water dissolved oxygen in an area. High inputs of labile organic material increase SOD and, subsequently, sulfate reduction rates and the associated abundance of sulfide end products. This results in more highly reduced, lower-reflectance sediments at depth and higher aRPD contrasts. In a region of generally low aRPD contrasts, images with high aRPD contrasts indicate localized sites of relatively large inputs of organic-rich material such as phytoplankton, other naturally-occurring organic detritus, dredged material, or sewage sludge.

Because the determination of the aRPD requires discrimination of optical contrast between oxidized and reduced particles, it is difficult, if not impossible, to determine the depth of the aRPD in well-sorted sands of any size that have little to no silt or organic matter in them. When using SPI technology on sand bottoms, little information other than grain-size, prism penetration depth, and boundary roughness values can be measured; while oxygen has no doubt penetrated the sand beneath the sediment-water interface just due to physical forcing factors acting on surface roughness elements (Ziebis et al., 1996; Huettel et al., 1998), estimates of the mean aRPD depths in these types of sediments are indeterminate with conventional white light photography.

2.1.7. Organic Loading, Sedimentary Methane, and Thiophilic Bacterial Colonies

If organic loading is extremely high, porewater sulfate is depleted and methanogenesis occurs. The process of methanogenesis is indicated by the appearance of methane bubbles in the sediment column. These gas-filled voids are readily discernable in SPI images because of their irregular, generally circular aspect and glassy texture (due to the reflection of the strobe off the gas bubble).

A primary diagnostic feature indicating an area is suffering from hypoxic conditions due to organic enrichment is the presence of the *Beggiatoa* or *Beggiatoa*-like colonies (note: while we cannot state with certainty that any bacterial colonies seen in profile images are indeed the genus *Beggiatoa* without microscopic identification, we can state with certainty that these are definitely in the same family of sulfur-oxidizing bacteria that only appear in hypoxic or anoxic conditions).

These colonies have diagnostic morphology that has been documented in numerous other sediment-profile imaging surveys (Karakassis et al. 2002; Nilsson and Rosenberg 1997; Rosenberg et al. 2001; Germano et al. 2011). The presence of sulfur-oxidizing bacterial colonies indicate hypoxic boundary-layer dissolved oxygen concentrations (Rosenberg and Diaz 1993).

2.1.8. Infaunal Successional Stage

The mapping of infaunal successional stages is readily accomplished with SPI technology. These stages are recognized in SPI images by the presence of dense assemblages of near-surface polychaetes and/or the presence of subsurface feeding voids; both may be present in the same image. Mapping of successional stages is based on the theory that organism-sediment interactions in fine-grained sediments follow a predictable sequence after a major seafloor perturbation. This theory states that primary succession results in "the predictable appearance of macrobenthic invertebrates belonging to specific functional types following a benthic disturbance. These invertebrates interact with sediment in specific ways. Because functional types are the biological units of interest..., our definition does not demand a sequential appearance of particular invertebrate species or genera" (Rhoads and Boyer 1982). This theory is presented in Pearson and Rosenberg (1978) and further developed in Rhoads and Germano (1982) and Rhoads and Boyer (1982).

This continuum of change in animal communities after a disturbance (primary succession) has been divided subjectively into four stages: Stage 0, indicative of a sediment column that is largely devoid of macrofauna, occurs immediately following a physical disturbance or in close proximity to an organic enrichment source; Stage 1 is the initial community of tiny, densely populated polychaete assemblages; Stage 2 is the start of the transition to head-down deposit feeders; and Stage 3 is the mature, equilibrium community of deep-dwelling, head-down deposit feeders (Figure 2-3).

After an area of bottom is disturbed by natural or anthropogenic events, the first invertebrate assemblage (Stage 1) appears within days after the disturbance. Stage 1 consists of assemblages of tiny tube-dwelling marine polychaetes that reach population densities of 10^4 to 10^6 individuals per m^2. These animals feed at or near the sediment-water interface and physically stabilize or bind the sediment surface by producing a mucous "glue" that they use to build their tubes. Sometimes deposited dredged material layers contain Stage 1 tubes still attached to mud clasts from their location of origin; these transported individuals are considered as part of the *in situ* fauna in our assignment of successional stages.

If there are no repeated disturbances to the newly colonized area, then these initial tube-dwelling suspension or surface-deposit feeding taxa are followed by burrowing, head-down deposit-feeders that rework the sediment deeper and deeper over time and mix oxygen from the overlying water into the sediment. The animals in these later-appearing communities (Stage 2 or 3) are larger, have lower overall population densities (10 to 100 individuals per m^2), and can rework the sediments to depths of 3 to 20 cm or more. These animals "loosen" the sedimentary fabric, increase the water content in the sediment, thereby lowering the sediment shear strength, and actively recycle nutrients because of the high exchange rate with the overlying waters resulting from their burrowing and feeding activities.

In dynamic estuarine and coastal environments, it is simplistic to assume that benthic communities always progress completely and sequentially through all four stages in accordance with the idealized conceptual model depicted in Figure 2-3. Various combinations of these basic successional stages are possible. For example, secondary succession can occur (Horn, 1974) in response to additional labile carbon input to surface sediments, with surface-dwelling Stage 1 or 2 organisms co-existing at the same time and place with Stage 3, resulting in the assignment of a "Stage 1 on 3" or "Stage 2 on 3" designation.

While the successional dynamics of invertebrate communities in fine-grained sediments have been well-documented, the successional dynamics of invertebrate communities in sand and coarser sediments are not well-known. Subsequently, the insights gained from sediment profile imaging technology regarding biological community structure and dynamics in sandy and coarse-grained bottoms are fairly limited.

2.1.9. Biological Mixing Depth

During the past three decades, there has been a considerable emphasis on studying the effects of bioturbation on sediment geotechnical properties as well as sediment diagenesis (Ekman et al., 1981; Nowell et al., 1981; Rhoads and Boyer, 1982; Grant et al., 1982; Boudreau, 1986; 1994; 1998). However, an increasing focus of research is centering on the rates of contaminant flux in sediments (Reible and Thibodeaux, 1999; François et al., 2002; Gilbert et al., 2003), and the two parameters that affect the time rate of contaminant flux the greatest are erosion and bioturbation (Reible and Thibodeaux, 1999). The depth to which sediments are bioturbated, or the biological mixing depth, can be an important parameter for studying either nutrient or contaminant flux in sediments. While the aRPD is one potential measure of biological mixing depth, it is quite common in profile images to see evidence of biological activity (burrows, voids, or actual animals) well below the mean aRPD. Both the minimum and maximum linear distance from the sediment surface to both the shallowest and deepest feature of biological activity are measured. From these, either the minimum, maximum, or average biological mixing depth can be mapped across a surveyed area of interest.

2.1.10. Organism-Sediment Index

The Organism-Sediment Index (OSI) is a summary mapping statistic that is calculated on the basis of four independently measured SPI parameters: mean aRPD depth, presence of methane gas, low/no dissolved oxygen at the sediment-water interface, and infaunal successional stage. Table 1 shows how these parameters are summed to derive the OSI.

The highest possible OSI is +11, which reflects a mature benthic community in relatively undisturbed conditions (generally a good yardstick for high benthic habitat quality). These conditions are characterized by deeply oxidized sediment with a low inventory of anaerobic metabolites and low SOD, and by the presence of a climax (Stage 3) benthic community. The lowest possible OSI is -10, which indicates that the sediment has a high inventory of anaerobic metabolites, has a high oxygen demand, and is azoic. In our experience using the OSI for over 15 years, we have found that OSI values of 6 or less indicate that the benthic habitat has experienced physical disturbance, organic enrichment, or excessive bioavailable contamination in the recent past.

Table 1. Calculation of the SPI Organism-Sediment Index (OSI)

Parameter	Index Value
A. Mean RPD Depth (choose one)	
0.00 cm	0
>0 – 0.75 cm	1
0.76 – 1.50 cm	2
1.51 – 2.25 cm	3
2.26 – 3.00 cm	4
3.01 – 3.75 cm	5
> 3.75 cm	6
B. Successional Stage (choose one)	
Azoic	-4
Stage 1	1
Stage 1 → 2	2
Stage 2	3
Stage 2 → 3	4
Stage 3	5
Stage 1 on 3	5
Stage 2 on 3	5
C. Chemical Parameters (choose all that apply)	
Methane Present	-2
No/Low Dissolved Oxygen	-4

Organism-Sediment Index = Total of above subset indices (A+B+C)
Range: -10 to +11

[a] This is not based on a Winkler or polarographic electrode measurement, but on the imaged evidence of reduced, low reflectance (i.e., high-oxygen-demand) sediment at the sediment-water interface.

2.2. USING SPI DATA TO ASSESS BENTHIC QUALITY & HABITAT CONDITIONS

While various measurements of water quality such as dissolved oxygen, contaminants, or nutrients are often used to assess regional ecological quality, interpretation is difficult because of the transient nature of water-column phenomena. Measurement of a particular value of any water-column variable represents an instantaneous "snapshot" that can change within minutes after the measurement is taken. By the time an adverse signal in the water column such as a low dissolved oxygen concentration is persistent, the system may have degraded to the point where resource managers can do little but map the spatial extent of the phenomenon while gaining a minimal understanding of factors contributing to the overall degradation.

The seafloor, on the other hand, is a long-term time integrator of sediment and overlying water quality; values for any variable measured are the result of physical, chemical, and biological interactions on time scales much longer than those present in a rapidly moving fluid. The seafloor is thus an excellent indicator of environmental quality, both in terms of historical impacts and of future trends for any particular variable.

Physical measurements from profile images provide background information about gradients in physical disturbance (caused by dredging, disposal, oil platform cuttings and drilling muds discharge, trawling, or storm resuspension and transport) in the form of maps of sediment grain size, boundary roughness, sediment textural fabrics, and structures. The concentration of organic matter and the SOD can be inferred from the optical reflectance of the sediment column and the aRPD depth. Organic matter is an important indicator of the relative value of the sediment as a carbon source for both bacteria and infaunal deposit feeders. SOD is an important measure of ecological quality; oxygen can be depleted quickly in sediment by the accumulation of organic matter and by bacterial respiration, both of which place an oxygen demand on the porewater and compete with animals for a potentially limited oxygen resource (Kennish 1986).

The aRPD depth is useful in assessing the quality of a habitat for epifauna and infauna from both physical and biological points of view. The aRPD depth in profile images has been shown to be directly correlated to the quality of the benthic habitat in polyhaline and mesohaline estuarine zones (Rhoads and Germano 1986; Revelas et al. 1987; Valente et al. 1992). Controlling for differences in sediment type and physical disturbance factors, aRPD depths < 1 cm can indicate chronic benthic environmental stress or recent catastrophic disturbance.

The distribution of successional stages in the context of the mapped disturbance gradients is one of the most sensitive indicators of the ecological quality of the seafloor (Rhoads and Germano 1986). The presence of Stage 3 equilibrium taxa (mapped from subsurface feeding voids as observed in profile images) can be a good indication of high benthic habitat stability and relative quality. A Stage 3 assemblage indicates that the sediment surrounding these organisms has not been disturbed severely in the recent past and that the inventory of bioavailable contaminants is relatively small. These inferences are based on past work, primarily in temperate latitudes, showing that Stage 3 species are relatively intolerant to sediment disturbance, organic enrichment, and sediment contamination. Stage 3 species expend metabolic energy on sediment bioturbation (both particle advection and porewater irrigation) to control sediment properties, including porewater profiles of sulfate, nitrate, and RPD depth in the sedimentary matrix near their burrows or tubes (Aller and Stupakoff 1996; Rice and Rhoads 1989). This bioturbation results in an enhanced rate of decomposition of polymerized organic matter by stimulating microbial decomposition ("microbial gardening"). Stage 3 benthic assemblages are very stable and are also called climax or equilibrium seres.

The metabolic energy expended in bioturbation is rewarded by creating a sedimentary environment where refractory organic matter is converted to usable food. Stage 3 bioturbation has been likened to processes such as stirring and aeration used in tertiary sewage treatment plants to accelerate organic decomposition. These processes can be interpreted as a form of human bioturbation. Physical disturbance, contaminant loading, and/or over-enrichment result in habitat destruction and in local extinction of the climax seres. Loss of Stage 3 species results in the loss of sediment stirring and aeration and may be followed by a buildup of organic matter (sediment eutrophication). Because Stage 3 species tend to have relatively conservative rates of recruitment, intrinsic population increase, and ontogenetic growth, they may not reappear for several years once they are excluded from an area.

The presence of Stage 1 seres (in the absence of Stage 3 seres) can indicate that the bottom is an advanced state of organic enrichment, has received high contaminant loading, or experienced a substantial physical disturbance. Unlike Stage 3 communities, Stage 1 seres have a relatively high tolerance for organic enrichment and contaminants. These opportunistic species have high rates of recruitment, high ontogenetic growth rates, and live and feed near the sediment-water interface, typically in high densities. Stage 1 seres often co-occur with Stage 3 seres in marginally enriched areas. In this case, Stage 1 seres feed on labile organic detritus settling onto the sediment surface, while the subsurface Stage 3 seres tend to specialize on the more refractory buried organic reservoir of detritus.

Stage 1 and 3 seres have dramatically different effects on the geotechnical properties of the sediment (Rhoads and Boyer 1982). With their high population densities and their feeding efforts concentrated at or near the sediment-water interface, Stage 1 communities tend to bind fine-grained sediments physically, making them less susceptible to resuspension and transport. Just as a thick cover of grass will prevent erosion on a terrestrial hillside, so too will these dense assemblages of tiny polychaetes serve to stabilize the sediment surface. Conversely, Stage 3 taxa increase the water content of the sediment and lower its shear strength through their deep burrowing and pumping activities, rendering the bottom more susceptible to erosion and resuspension. In shallow areas of fine-grained sediments that are susceptible to storm-induced or wave orbital energy, it is quite possible for Stage 3 taxa to be carried along in the water column in suspension with fluid muds. When redeposition occurs, these Stage 3 taxa can become quickly re-established in an otherwise physically disturbed surface sedimentary fabric.

SPI has been shown to be a powerful reconnaissance tool that can efficiently map gradients in sediment type, biological communities, or disturbances from physical forces or organic enrichment (Germano et al. 2011). The conclusions reached at the end of this report are about dynamic processes that have been deduced from imaged structures; as such, they should be considered hypotheses available for further testing/confirmation. By employing Occam's Razor, we feel reasonably assured that the most parsimonious explanation is usually the one borne out by subsequent data confirmation.

3.0 RESULTS

The SPI survey performed this year (Year 10 monitoring) in the Thea Foss and Wheeler-Osgood Waterways was conducted to track the post-remediation progress of benthic recolonization. Benthic habitat conditions were altered by historical contamination along with the sediment dredging and capping actions completed in the waterways. As stated in the OMMP, given the habitat improvements resulting from the completed remedial actions, the waterway is expected to be re-colonized by benthic infauna and epifauna common to the reference environment found in Commencement Bay (City of Tacoma et al. 2006).

The SPI parameters will be discussed with the overall average and maximum sample values examined first, and then the remedial areas will be compared to one another throughout the waterway, generally in the order from the Commencement Bay side to the inner channel towards the SR 509 Bridge.

A complete set of all the summary data measured from each image is presented in Appendix A; a DVD with digital files of the sediment profile images in Joint Photographic Experts Group high resolution format (*.jpg) has been provided under separate cover to the client.

The results for some SPI parameters are sometimes indicated in the data appendix or on the maps as being "Indeterminate" (IND). This is a result of the sediments being either: 1) too compact for the profile camera to penetrate adequately, preventing observation of surface or subsurface sediment features (preventing either accurate measurement of the aRPD or determination of the infaunal successional stage), 2) too soft to bear the weight of the camera, resulting in over-penetration to the point where the sediment/water interface was above the window (imaging area) on the camera prism (the sediment/water interface must be visible to measure most of the key SPI parameters like aRPD depth, penetration depth, and infaunal successional stage), or 3) the sediment consisted of light-colored sand lacking a visible aRPD contrast and for which infaunal successional dynamics, generally speaking, are not well-known. While four replicate images generally were taken at each station, only three replicate images from each station were analyzed for this report; the first three images that had optimal penetration for that particular location were chosen for analysis.

Parameters such as boundary roughness and mud clast data provide supplemental information pertaining to the physical regime and bottom sediment transport activity at a site. Small reduced and oxidized mud clasts were observed at several stations (Appendix A) and may indicate biogenic activity and local sediment dynamics. Even though mud clasts are definitive characteristics whose presence can indicate physical disturbance of some form, generally the mud clasts in the images from this survey were artifacts due to sampling (mud clumps clinging to the frame base or camera wiper blade) and not indicative of physical disturbance or sediment transport activities. Therefore, mud clast data were not used as individual parameters for interpretation.

3.1. GRAIN SIZE

Sediments throughout the entire area surveyed had a base of fine-grained silt and clays (Figure 3-1), with the exception of two stations (BR26 and BR29) at which the substrate was predominately very fine sand (Figure 3-2). Eleven stations had a surface layer of silty, very fine to fine sand (Figure 3-3). Two of the replicate images from BR31 had coarser particles (coarse sand to pebble) at the surface and extending a few centimeters below the surface, indicating that the sand and gravel cap used as a remedial alternative in this location is still visible and has not been covered with additional sediment deposition (Figure 3-4).

3.2. SURFACE BOUNDARY ROUGHNESS

Average station surface boundary roughness ranged from 0.41 cm to 2.20 cm (Figure 3-5), with the majority of small-scale topographic roughness elements caused by biogenic processes (Appendix A). The overall average surface boundary roughness for the entire survey area was 1.13 cm.

The average surface boundary roughness values by remediation area were:

Remedial Area (# of Stations)	2008 Average Surface Boundary Roughness (cm)	2010 Average Surface Boundary Roughness (cm)	2013 Average Surface Boundary Roughness (cm)	2016 Average Surface Boundary Roughness (cm)
Background/No Action (4)	1.07	0.75	0.90	1.02
Natural Recovery (5)	0.91	0.88	0.73	0.83
Enhanced Natural Recovery (1)	1.16	0.48	0.79	1.01
Dredge to Clean (4)	1.00	1.22	0.98	1.32
Channel Sand Cap (7)	1.59	1.16	1.10	1.33

3.3. SURFACE DEPOSITIONAL LAYER THICKNESS

While the entire waterway is essentially a depositional basin and slowly accreting, during the 2008 and 2010 surveys, there were distinct sedimentary layers from recent depositional events that were visible in the profile images. In the 2016 survey, as in preceding 2013 survey, there were no distinct depositional intervals detected in the profile images; bioturbation activity was apparently more intense than in past years, and any accreting sediments were mixed into the existing sediment column by resident infauna.

3.4. PRISM PENETRATION DEPTH

Because the camera stop collar and weight settings were changed several times during the course of the survey due to variation in bottom sediment type, the range of average station prism penetration depths displayed across the entire survey area (Figure 3-6) was due to differences in relative sediment shear strength (from varying sediment grain-size major mode and range, depth of bioturbation, etc.) as well as differences in the camera settings (Appendix A). Sediments at Station BR09 had the lowest shear strength, with only 1 weight used in each of the camera weight carriages at this location (Appendix A). The shallowest camera penetration values were at three locations (BR26, BR29, and BR31) in the sand and gravel cap remediation area that lacked the base of silt/clay found at other locations (Figures 3-2 and 3-4).

The overall average station prism penetration depth in the study area ranged from 5.34 cm to 17.69 cm (Figure 3-6), with an overall site average of 13.26 cm. The average camera prism penetration depths by remedial areas were:

Remedial Area (# of Stations)	2008 Average Camera Prism Penetration (cm)	2010 Average Camera Prism Penetration (cm)	2013 Average Camera Prism Penetration (cm)	2016 Average Camera Prism Penetration (cm)
Background/No Action (4)	11.34	12.91	12.00	12.19
Natural Recovery (5)	11.39	15.23	12.79	14.89
Enhanced Natural Recovery (1)	9.50	13.40	12.18	14.79
Dredge to Clean (4)	12.60	15.55	12.94	15.66
Channel Sand Cap (7)	10.70	11.40	11.83	11.10

3.5. APPARENT REDOX POTENTIAL DISCONTINUITY DEPTH

The distribution of mean apparent RPD (aRPD) depths ranged from a low of 0.78 cm found at Station BR16 to a high of 3.54 cm at Station BR28 (Figure 3-7). The overall station average aRPD depth for the site was 1.43 cm.

The average aRPD depths by remedial areas were:

Remedial Area (# of Stations)	2008 Average aRPD depth (cm)	2010 Average aRPD depth (cm)	2013 Average aRPD depth (cm)	2016 Average aRPD depth (cm)
Background/No Action (4)	2.77	2.49	2.98	1.59
Natural Recovery (5)	2.50	2.38	1.85	1.04
Enhanced Natural Recovery (1)	2.27	1.20	1.49	0.79
Dredge to Clean (4)	2.20	2.43	1.92	2.45
Channel Sand Cap (7)	1.78	1.69	1.41	1.11

Organically-enriched subsurface sediments contribute to low aRPD values (Figure 3-8). Five stations in this survey had aRPD values less than 1.0 cm: Stations BR07, BR11 and BR16 near the Foss Waterway Marina, Station 09 in the channel between the Foss Waterway Marina and Totem Marine, and Station BR21 in the channel near the mouth of the Wheeler-Osgood Waterway. Of the three stations in the 2013 survey with aRPD depths below 1.0 cm, BR22 showed marked improvement with a mean station aRPD of 3.15 cm, while BR10 and BR33 both improved marginally to a mean of just over 1 cm (1.01 cm at both stations).

Sulfur-oxidizing bacterial colonies (*Beggiatoa* spp.) were not seen at any stations in 2016. These white, filamentous bacterial colonies appear at the sediment surface when oxygen concentrations in the benthic boundary layer are hypoxic (Rosenberg and Diaz, 1993). In past surveys *Beggiatoa* was observed at Station BR23 and the presence of an aRPD at this station was noted as an improvement in the 2013 survey report. Conditions continue to improve at this location with no observed *Beggiatoa*, an aRPD greater than 1.0 cm, and Stage 3 fauna present in all images (Figure 3-9).

3.6. INFAUNAL SUCCESSIONAL STAGE

Stage 3 fauna were present in the majority of images (90%, 57 of 63 images) sampled with only images from two stations (BR29, BR31) showing no signs of Stage 3 taxa (Figure 3-10). This wide distribution of Stage 3 fauna throughout the survey area is similar to what was observed in all prior surveys (2008, 2010, 2013). Many stations were Stage 1 on 3 with small tube-building and burrowing fauna in the upper 1-2 cm of the sediment column and larger burrowing infauna at depth (Figure 3-11) or Stage 3 (Figure 3-12). Tubes of the surface-deposit feeder *Spiochaetopterus costarum* were seen at Stations BR26, BR31, and BR33 (Figure 3-13) indicating Stage 2 or transitional Stage 2 to 3 successional stages. Improvements in benthic community status were seen in the outer waterways in that several stations where in 2010 at least one replicate image showed transitional Stage 1 to 2 or Stage 2 to 3, all replicates at these stations showed Stage 3 taxa in the 2016 survey (Figure 3-10).

3.7. BIOLOGICAL MIXING DEPTH

Evidence of burrowing infauna and deposit feeding activity was present at the majority of stations surveyed and feeding voids observed in about three-quarters of the images analyzed (Appendix A). There were no feeding voids at 5 stations. Maximum bioturbation depths measured was from 4.95 cm at Station BR29 (due to shallow prism penetration) to 18.25 cm at Station BR06 (Figure 3-14). The overall average maximum bioturbation depth was 12.77 cm, with evidence of some relatively large infaunal burrowing organisms present (Figure 3-15).

The maximum depths (Appendix A) to which sediments were bioturbated by remediation area were:

Remedial Area (# of Stations)	2008 Maximum Bioturbation Depth (cm)	2010 Maximum Bioturbation Depth (cm)	2013 Maximum Bioturbation depth (cm)	2016 Maximum Bioturbation depth (cm)
Background/No Action (4)	13.57	13.43	13.23	13.06
Natural Recovery (5)	14.88	16.33	14.56	18.25
Enhanced Natural Recovery (1)	10.02	13.54	13.14	15.04
Dredge to Clean (4)	18.15	17.66	15.59	16.89
Channel Sand Cap (7)	18.86	15.26	20.05	15.69

3.8. ORGANISM SEDIMENT INDEX

Median OSI values were consistently high near the mouth of the waterway and more varied in the inner reaches of the waterways (Figure 3-16). The overall median OSI for the entire study area from the 2016 survey was +7, compared to an overall median of +8 measured in the last 3 surveys. Values ranging from a low of +5 (Stations BR29 and BR31) to a maximum value of +10 (Station BR28). An OSI of +6 or less typically indicates that a benthic habitat has experienced physical disturbances, eutrophication, or excessive bioavailable contamination in the recent past.

The lowest OSI value measured was at station BR16 and was due to organically-enriched sediments and the presence of methane bubbles (Figure 3-17). Five of the 21 stations sampled had a median station value below +7 (Figure 3-16).

The median OSI values by remediation area were as follows:

Remedial Area (# of Stations)	2008 Median OSI Value	2010 Median OSI Value	2013 Median OSI Value	2016 Median OSI Value
Background/No Action (4)	8	9	9	8
Natural Recovery (5)	8	8	8	7
Enhanced Natural Recovery (1)	9	7	7	7
Dredge to Clean (4)	9	9	8	8.5
Channel Sand Cap (7)	7.5	8	7	6

4.0 DISCUSSION

The primary objectives of this SPI survey were to document the physical nature of the benthic habitat and observable organism-sediment interactions at the sediment-water interface in the Thea Foss and Wheeler-Osgood Waterways and compare the results from this most recent survey with past surveys conducted in 2008, 2010, and 2013. While the data values from the various parameters measured look quite similar among the three surveys (the sample sizes are too small to perform any statistical comparisons except ones with very low power or detection of extremely large effect sizes), there are some noticeable qualitative differences at specific locations among the 4 survey periods:

- While the benthic habitats were similar for the entire area in 2008, there were marked differences in sediment type at certain stations in 2010 and in 2013. Specifically, Station BR18 showed evidence of the surface layer being eroded away (most likely from propwash effects). This pattern was not observed in the 2016 survey. The primary difference in sediment types in 2016 was the observation of very fine to fine sand and no silt/clay in the profile images for Stations BR26 and BR29.

- All of the remedial areas sampled showed evidence of mature infaunal communities in all four year of monitoring . As in the previous survey, there was continued improvement of habitat conditions at Station BR23 (Figure 3-9). Additionally, the average aRPD at Station BR44 improved from less than 1 cm in 2013 to greater than 3 cm in the 2016 survey (Figure 3-12).

- Unlike the 2008 and 2010 surveys, in the 2013 and 2016 surveys there were no indications of quantum sediment input that formed distinct depositional layers.

- In 2013, organic loading did not appear to be as severe as in the 2010 survey as indicated by the dramatic improvement at Stations BR23 and BR18. In 2013 conditions improved noticeably and Station BR33 was the only station that continued to show retrograde successional conditions and high sediment oxygen demand. In 2016, this station had improved to a transitional Stage 2 to 3 community. In 2016, evidence of organic loading was most notably at Station BR16 where aRPD values were less than 1 cm and methane bubbles were observed in the sediment column.

While the results from 2008 indicated that the completed remedial actions had a positive effect on benthic habitat quality, the 2010 results indicated there were degraded conditions at three locations in particular (BR18, BR23, and BR33). The 2013 showed improved benthic habitat quality at all locations with the exception of BR33. Although the 2016 survey showed evidence of organic loading and high sediment oxygen demand (stations with aRPDs < 1 cm), the benthic communities present appear to be able to balance these demands and persist in all remediation areas in the Thea Foss and Wheeler-Osgood Waterways.

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FIGURES

for

Year 10 Benthic Recolonization Monitoring of the Thea Foss and Wheeler-Osgood Waterways: Sediment-Profile Imaging Survey/ July 2016

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List of Figures

Figure 1-1. Location of Thea Foss and Wheeler-Osgood Waterways, Tacoma, WA

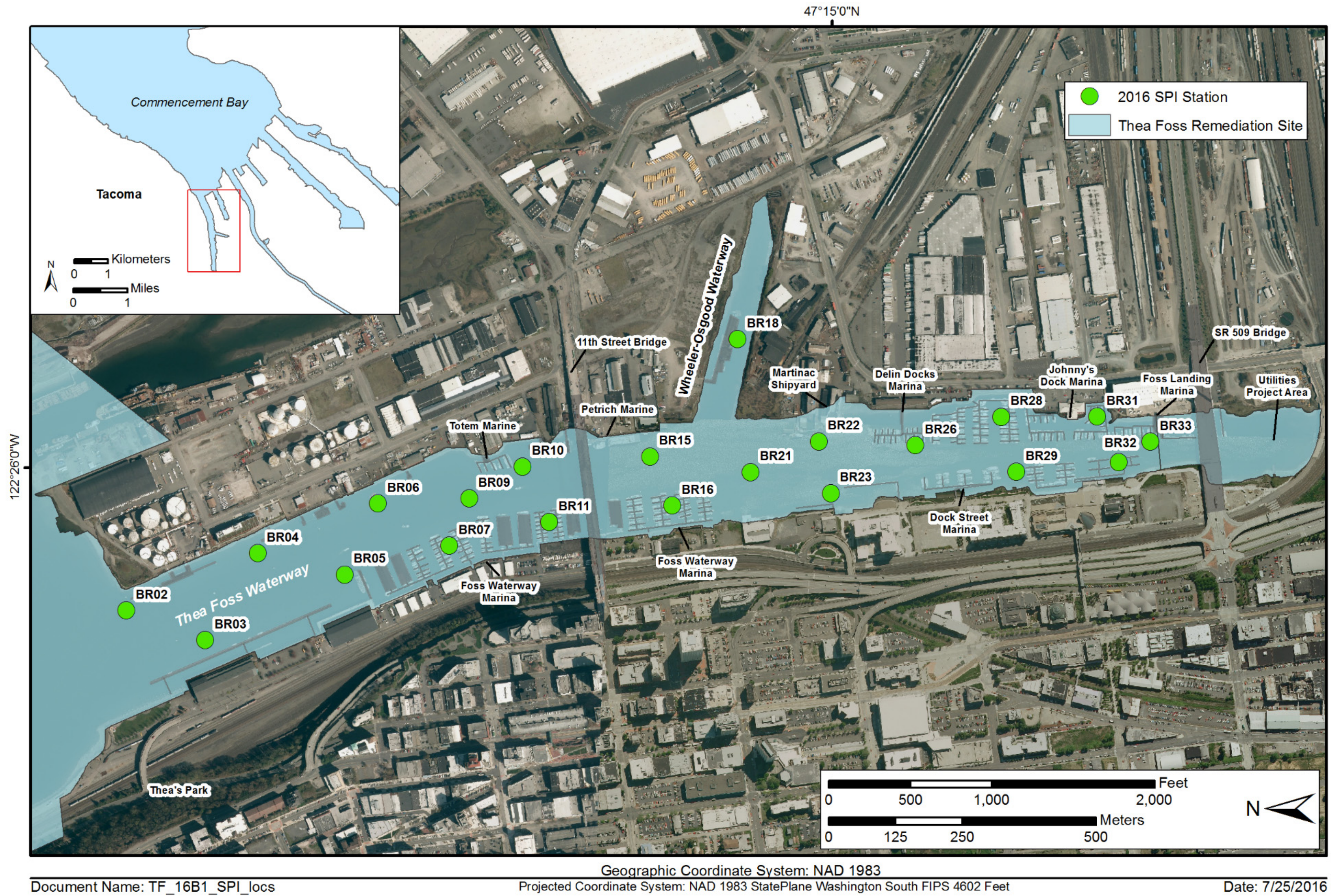


Figure 2-1. Location of SPI sampling stations in the Thea Foss and Wheeler-Osgood Waterways

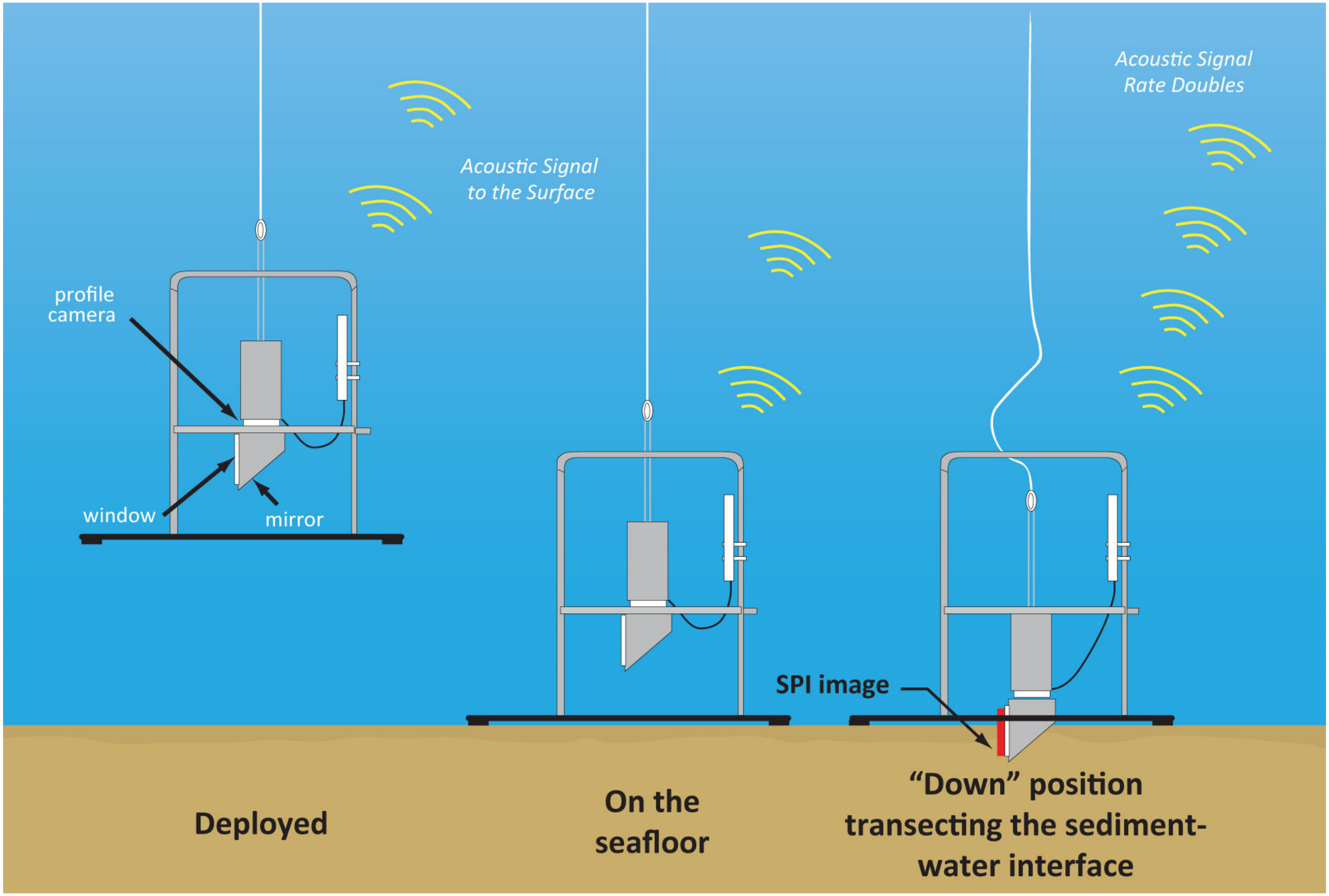


Figure 2-2. Operation of the combined sediment-profile and plan-view camera imaging system

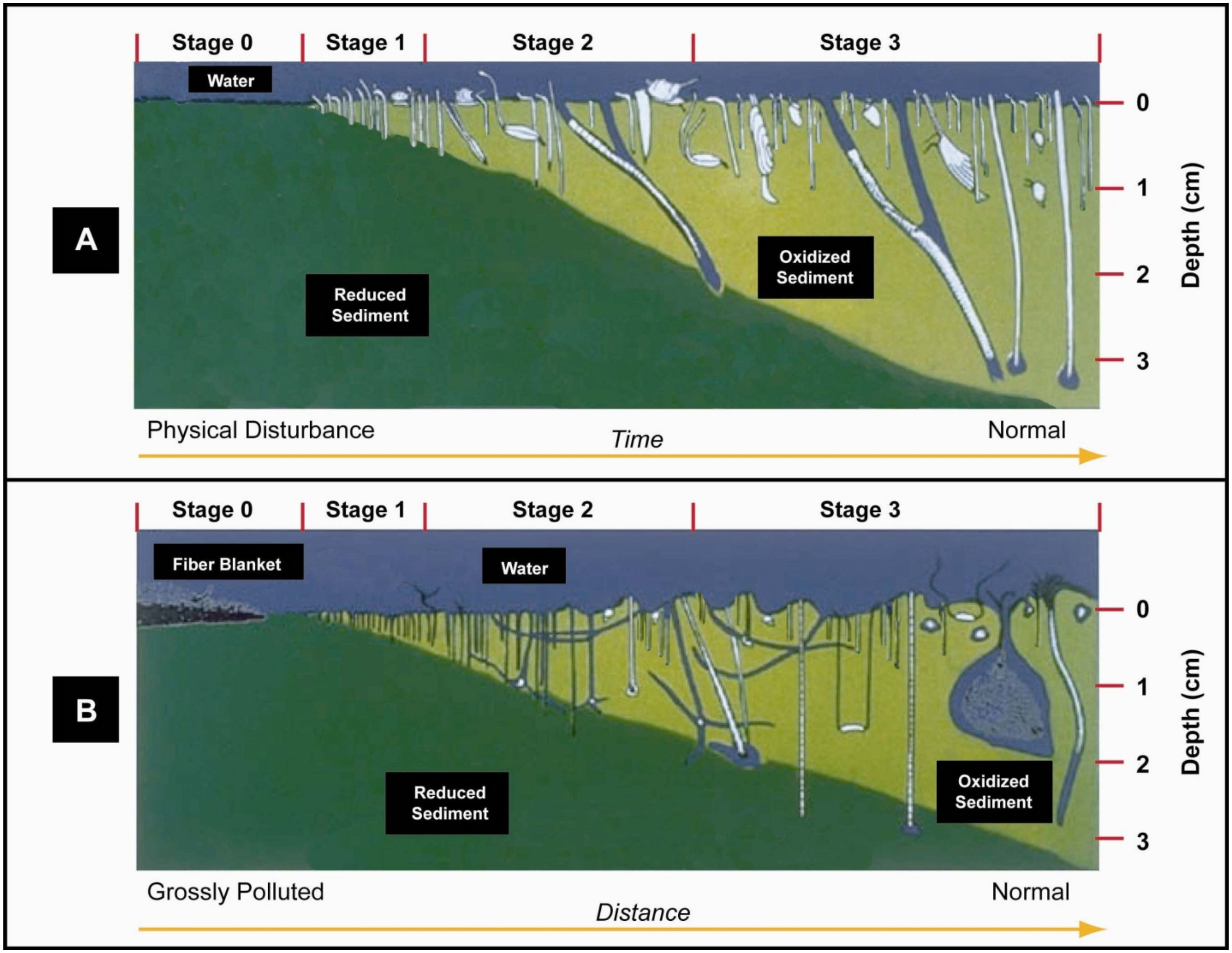


Figure 2-3. The stages of infaunal succession as a response of soft-bottom benthic communities to (A) physical disturbance or (B) organic enrichment; from Rhoads and Germano (1982)

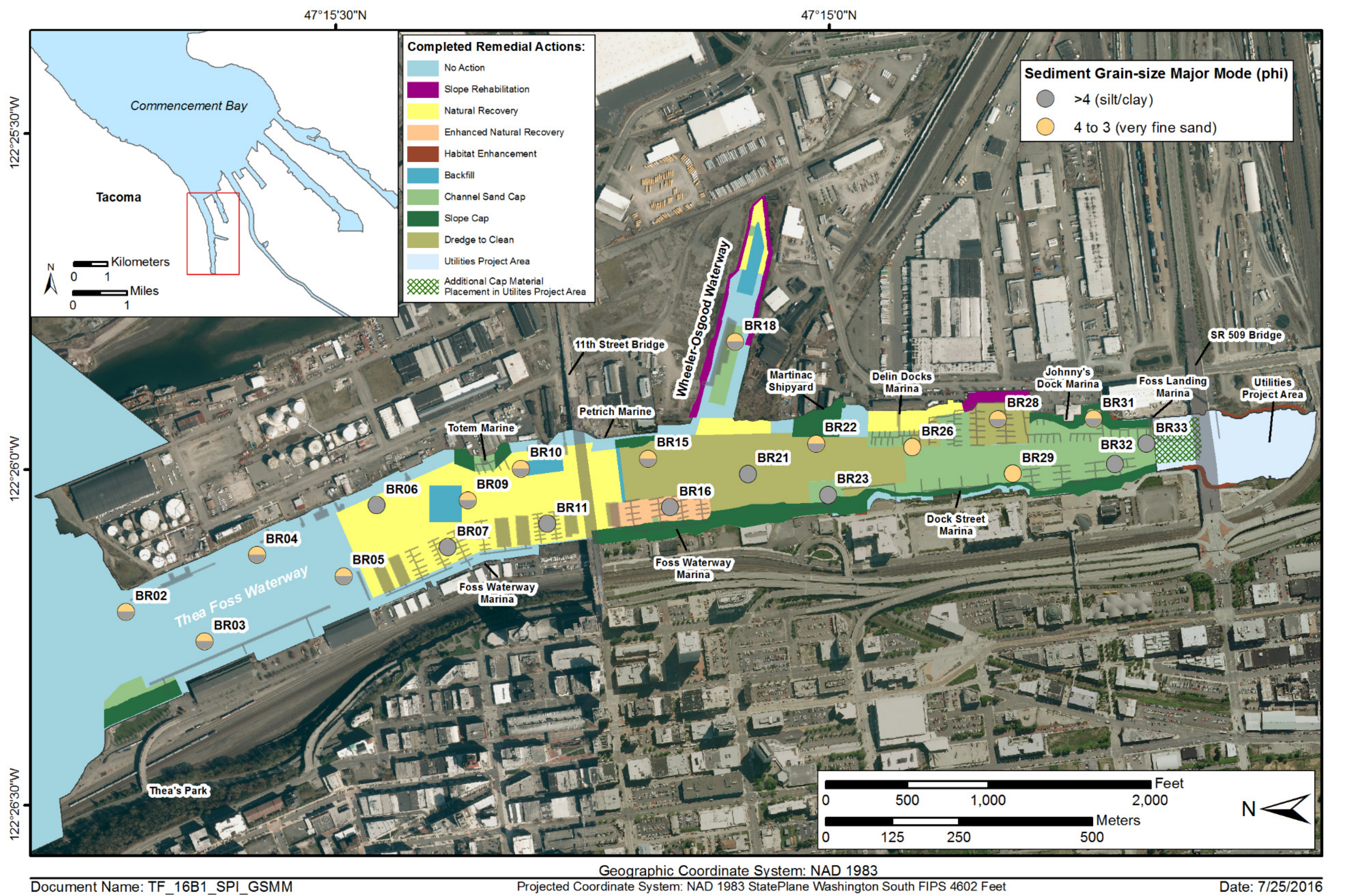


Figure 3-1. Spatial distribution of sediment grain-size major modes (phi) at stations in the Thea Foss and Wheeler-Osgood Waterways

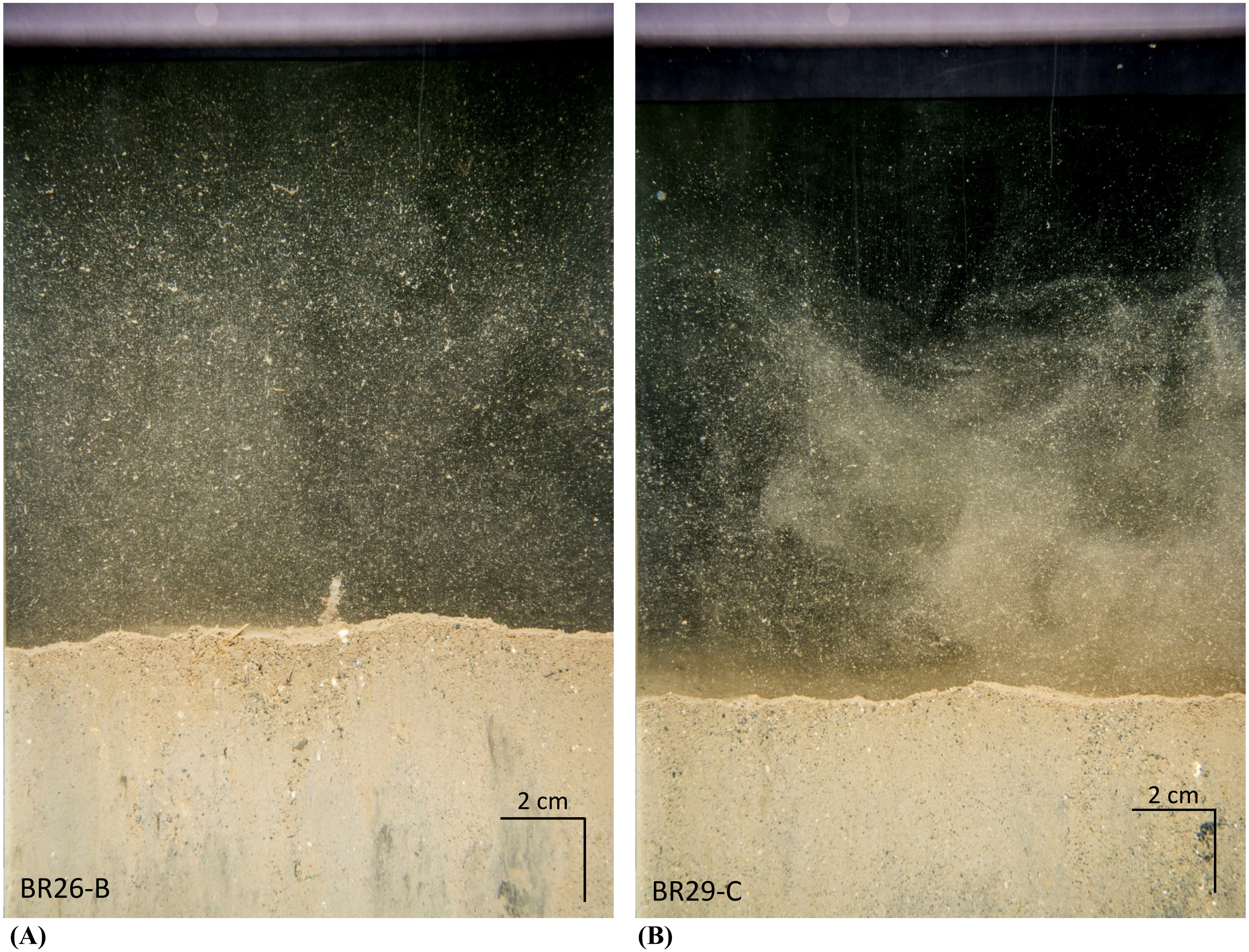
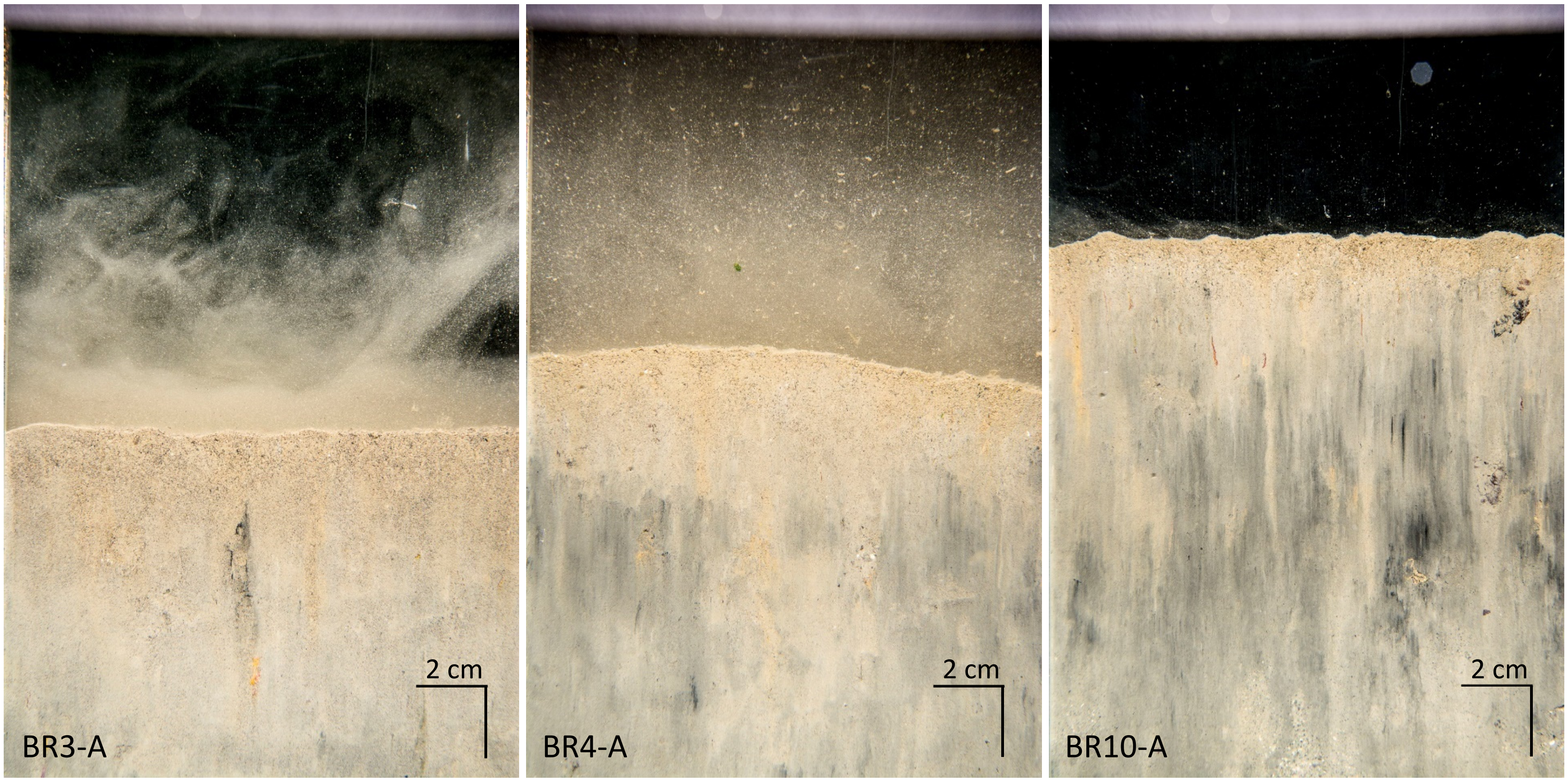


Figure 3-2. Profile images from sand cap locations (A) Station BR26 and (B) Station BR29 with very fine sand and relatively shallow prism penetration (6.72 and 5.21 cm, respectively)



(A) **(B)** **(C)**

Figure 3-3. Profile images from (A) Station BR3, (B) Station BR4, and (C) Station BR10 from the waterway mouth to the 11 Street Bridge showing distinct enrichment of very fine to fine sand in the upper 1-2 cm of the sediment surface

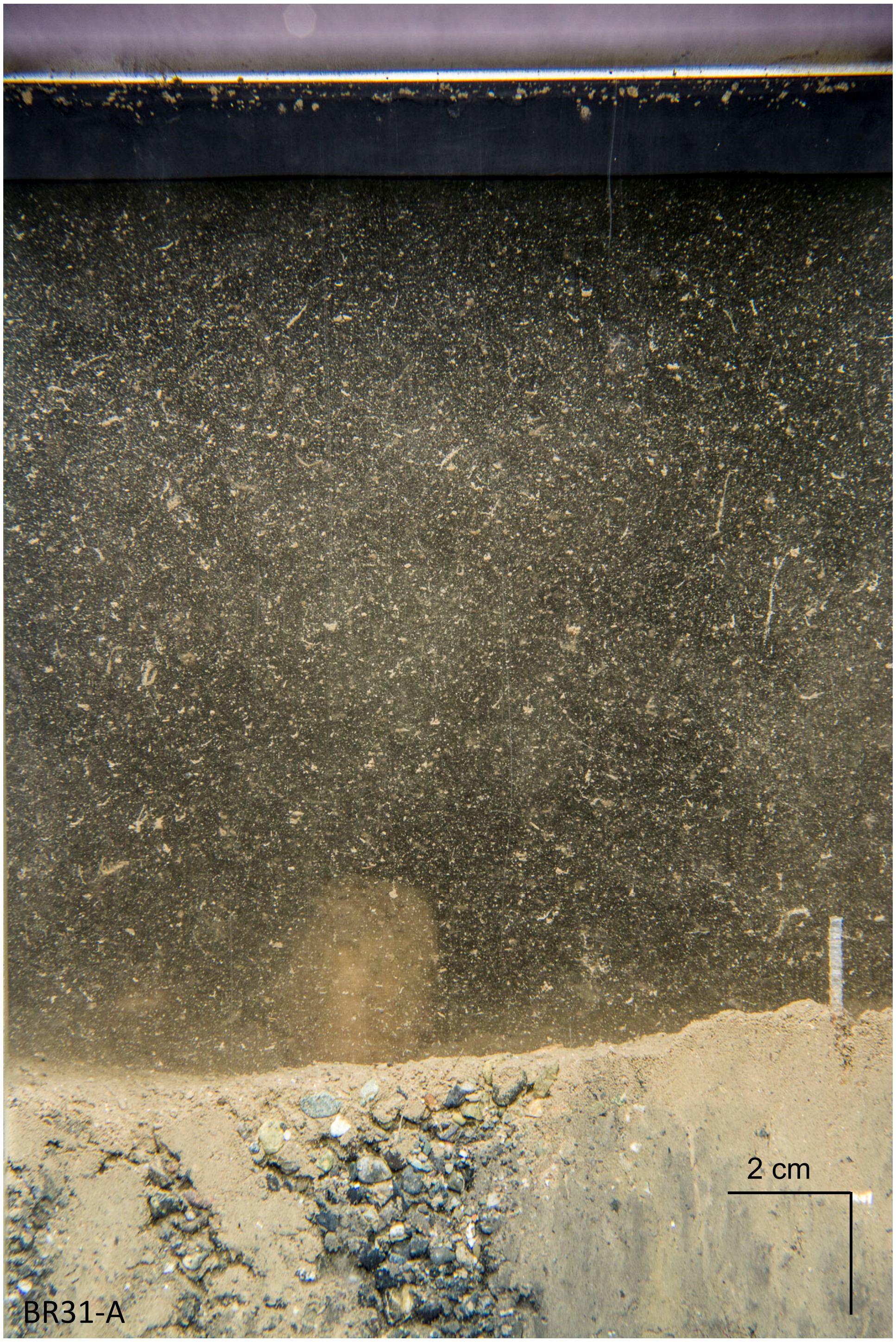


Figure 3-4. Profile image from Station BR31 continues to show little evidence of additional deposition with evidence of the sand cap still visible 10 years after placement

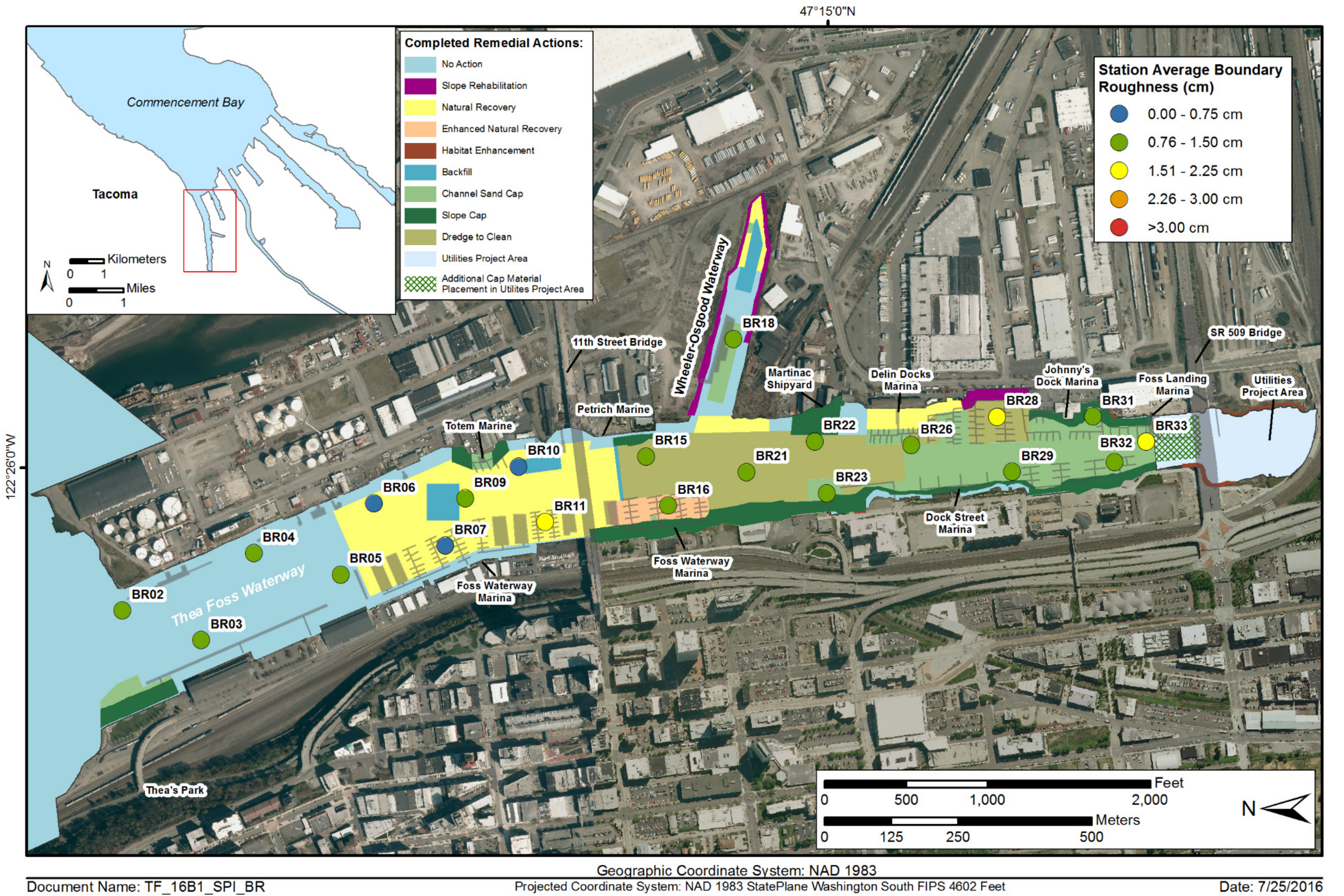


Figure 3-5. Spatial distribution of average boundary roughness values (cm) at stations in the Thea Foss and Wheeler-Osgood Waterways

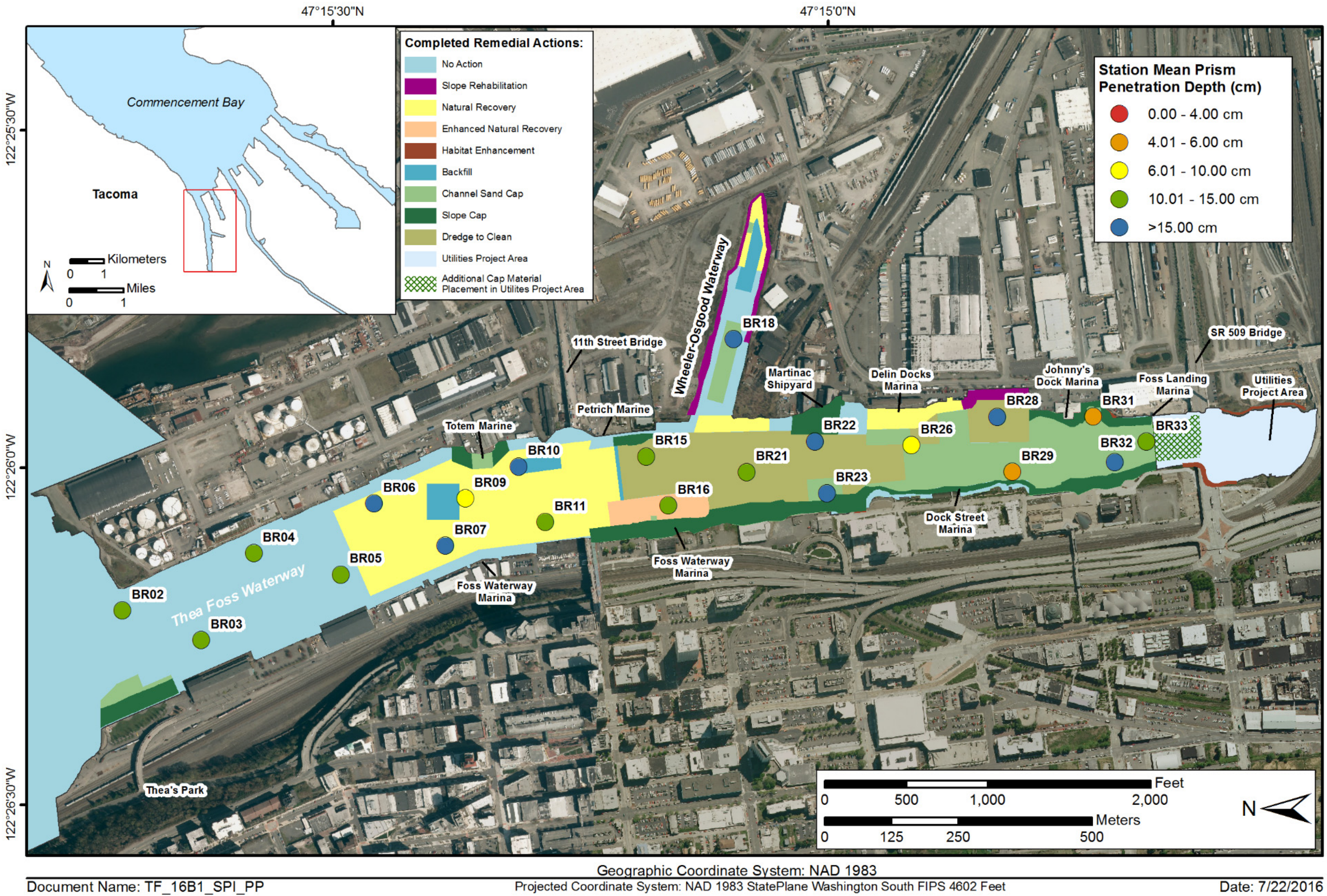


Figure 3-6. Spatial distribution of mean prism penetration depths (cm) at stations in the Thea Foss and Wheeler-Osgood Waterways

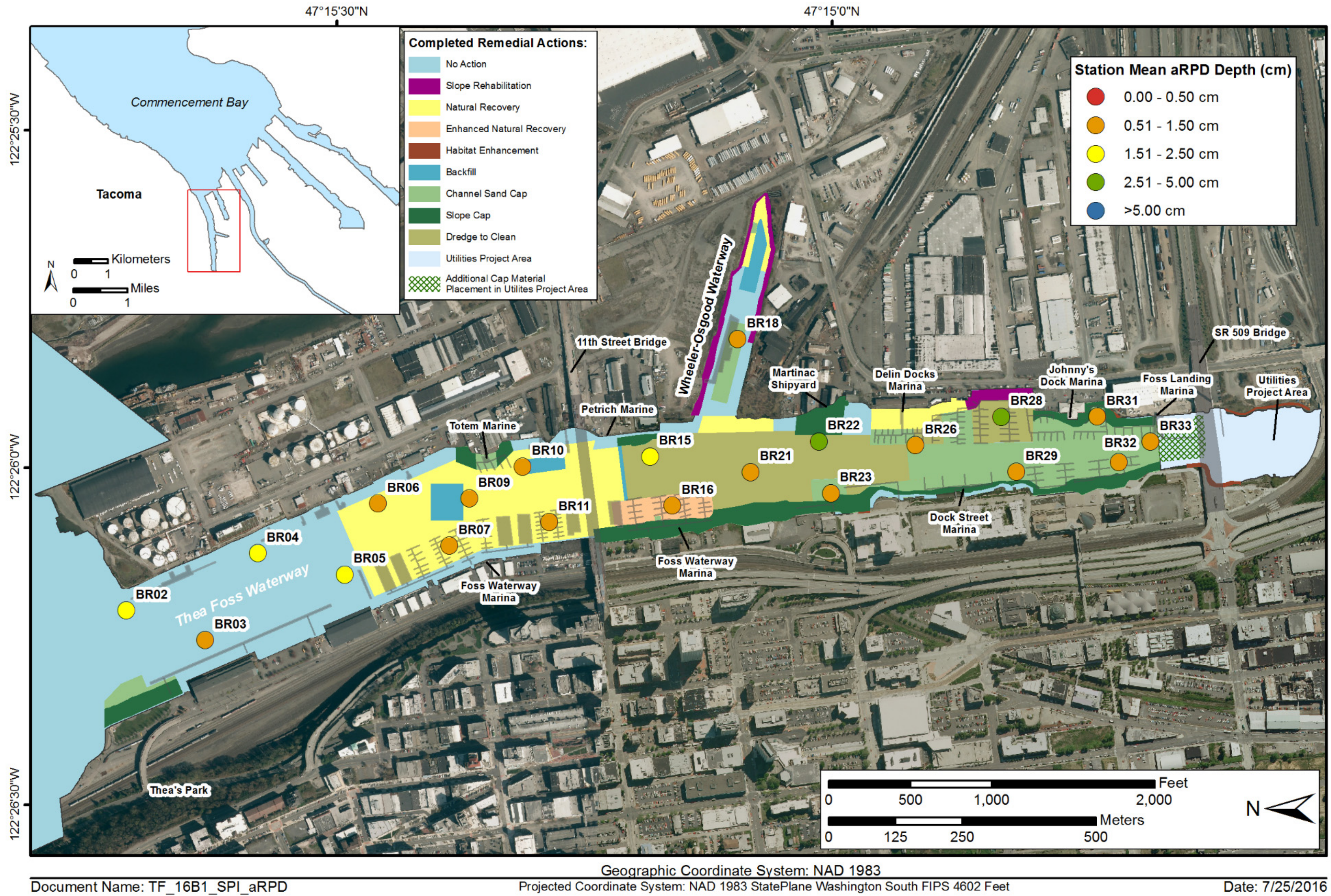
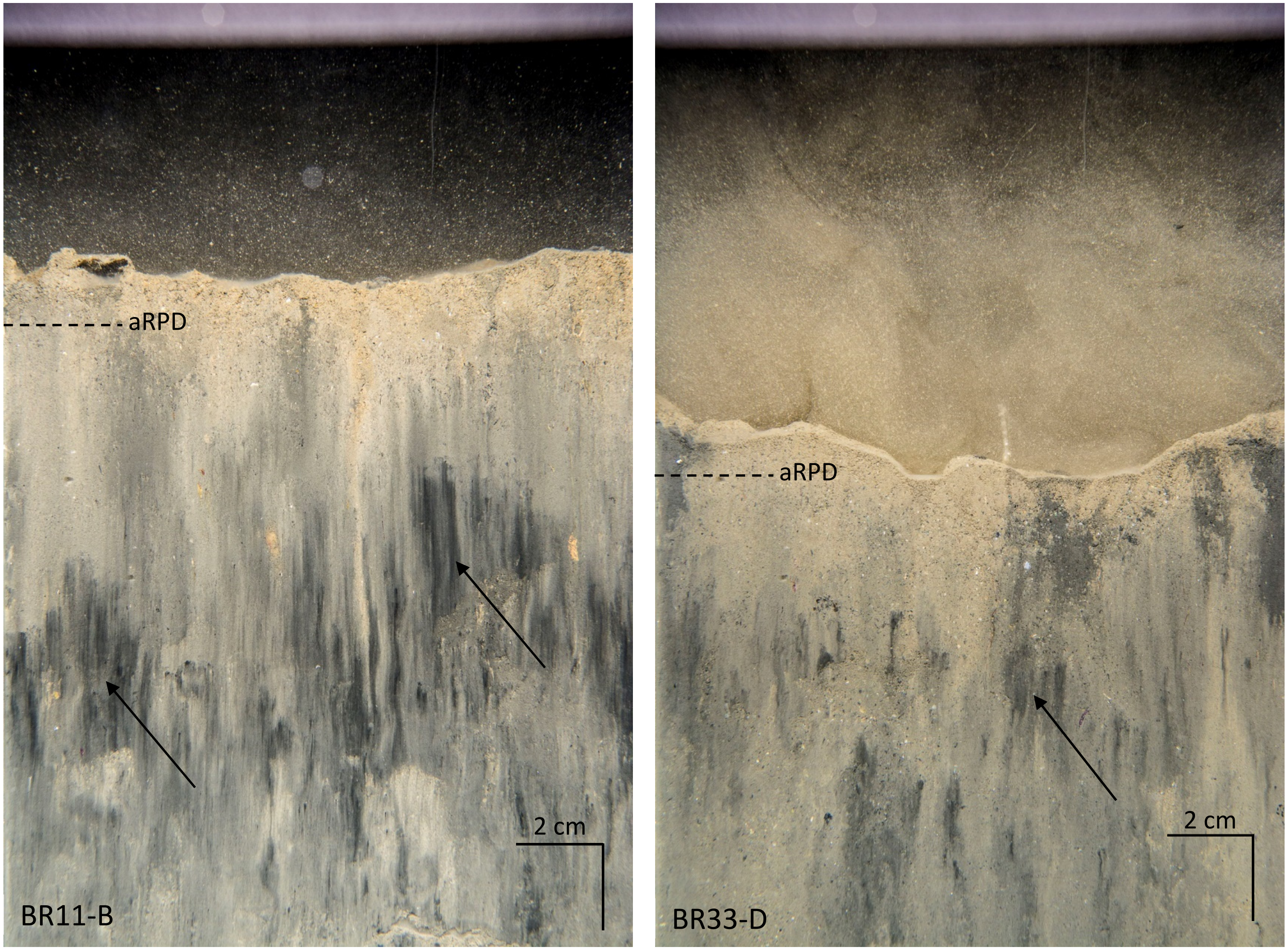
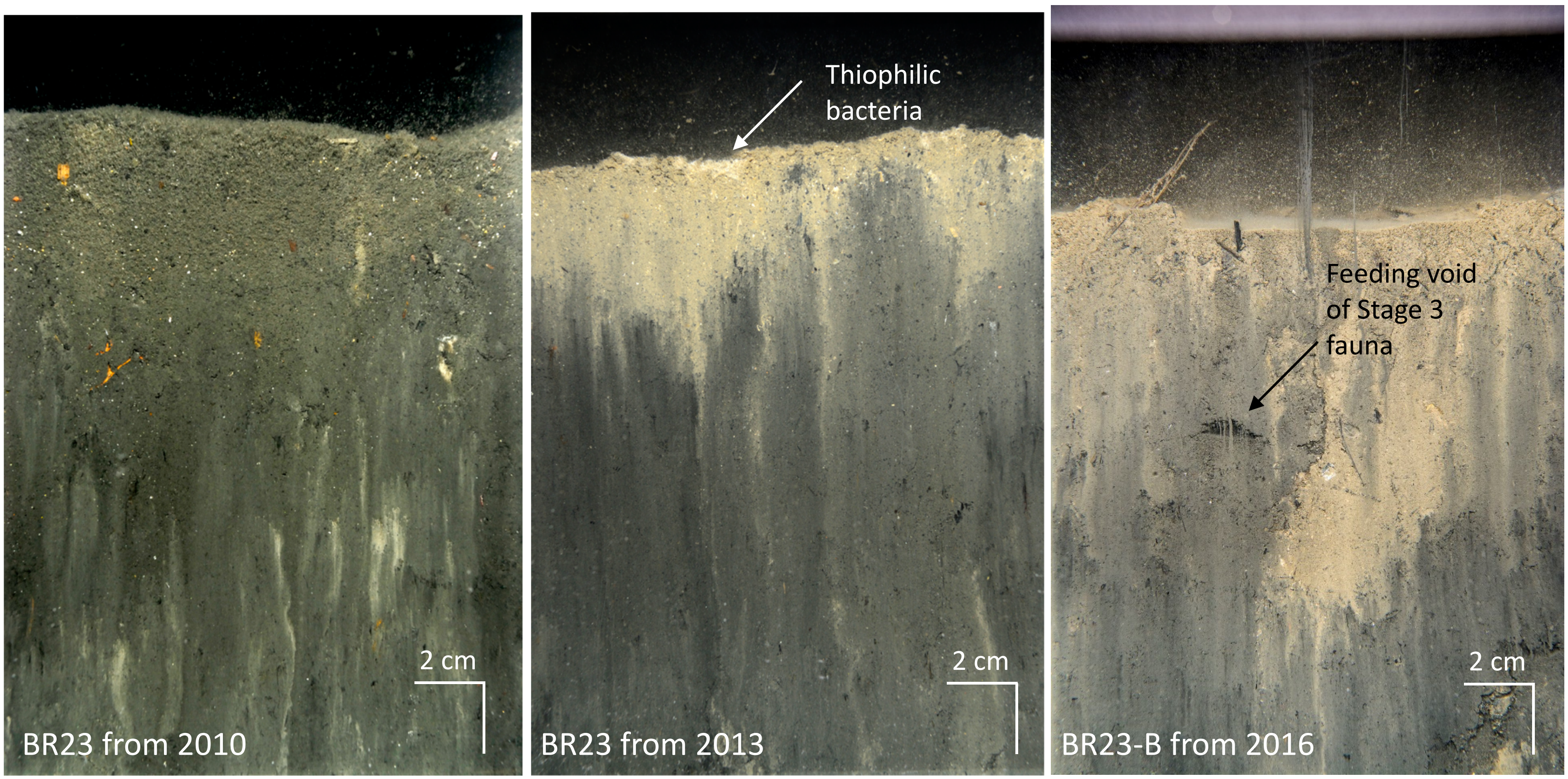


Figure 3-7. Spatial distribution of mean aRPD depths (cm) at stations in the Thea Foss and Wheeler-Osgood Waterways



(A) (B)

Figure 3-8. Profile images from (A) Station BR11 and (B) Station 33 showing organically-enriched subsurface sediments (arrows) which contributed to low aRPD depths (0.96 and 0.79 cm, respectively)



(A) **(B)** **(C)**

Figure 3-9. Profile images from Station BR23 in (A) 2010, (B) 2013, and (C) 2016, where conditions continue to improve with no evidence of thiophilic bacteria and continued presence of Stage 3 taxa

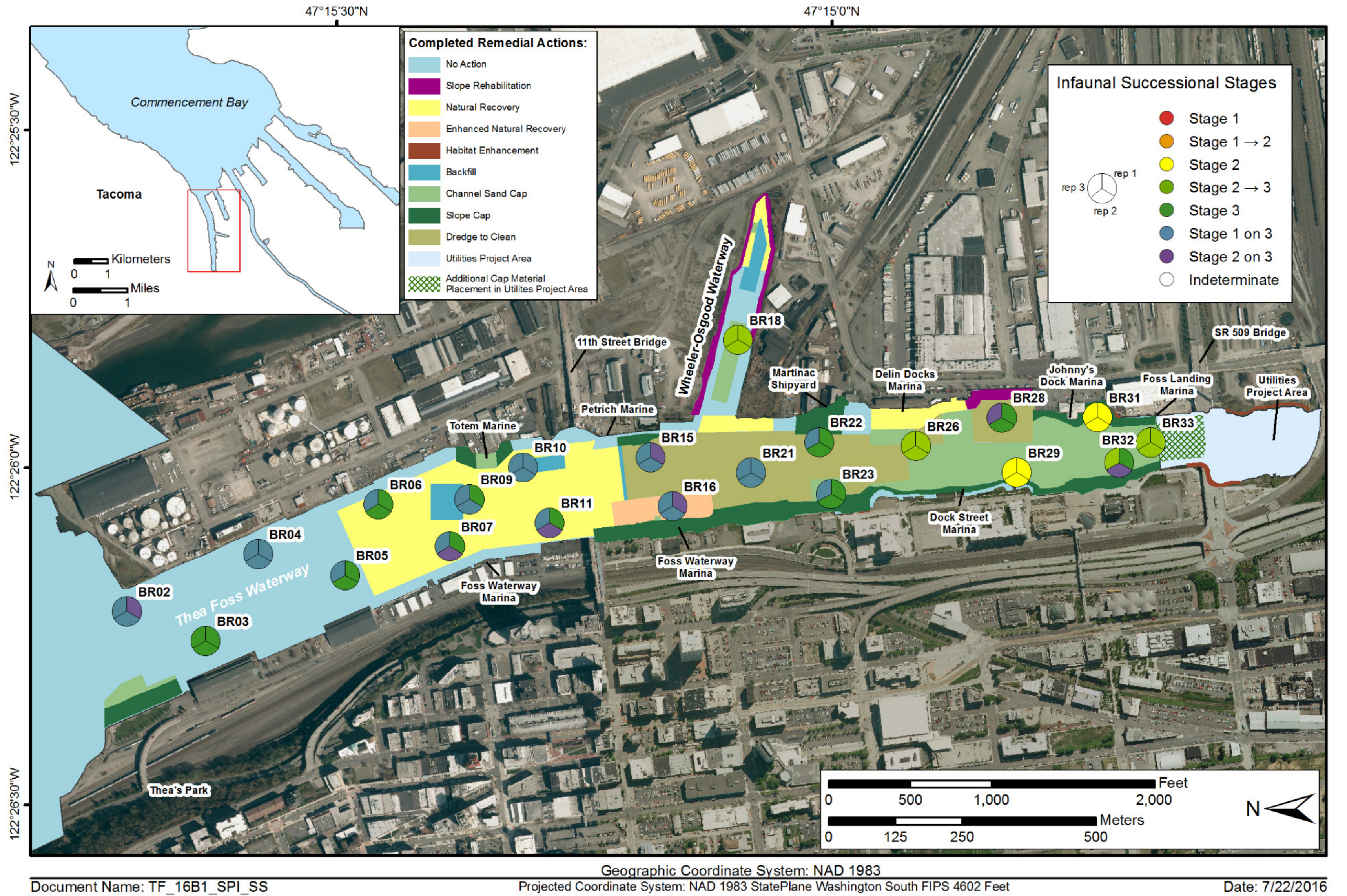


Figure 3-10. Spatial distribution of infaunal successional stages at stations in the Thea Foss and Wheeler-Osgood Waterways

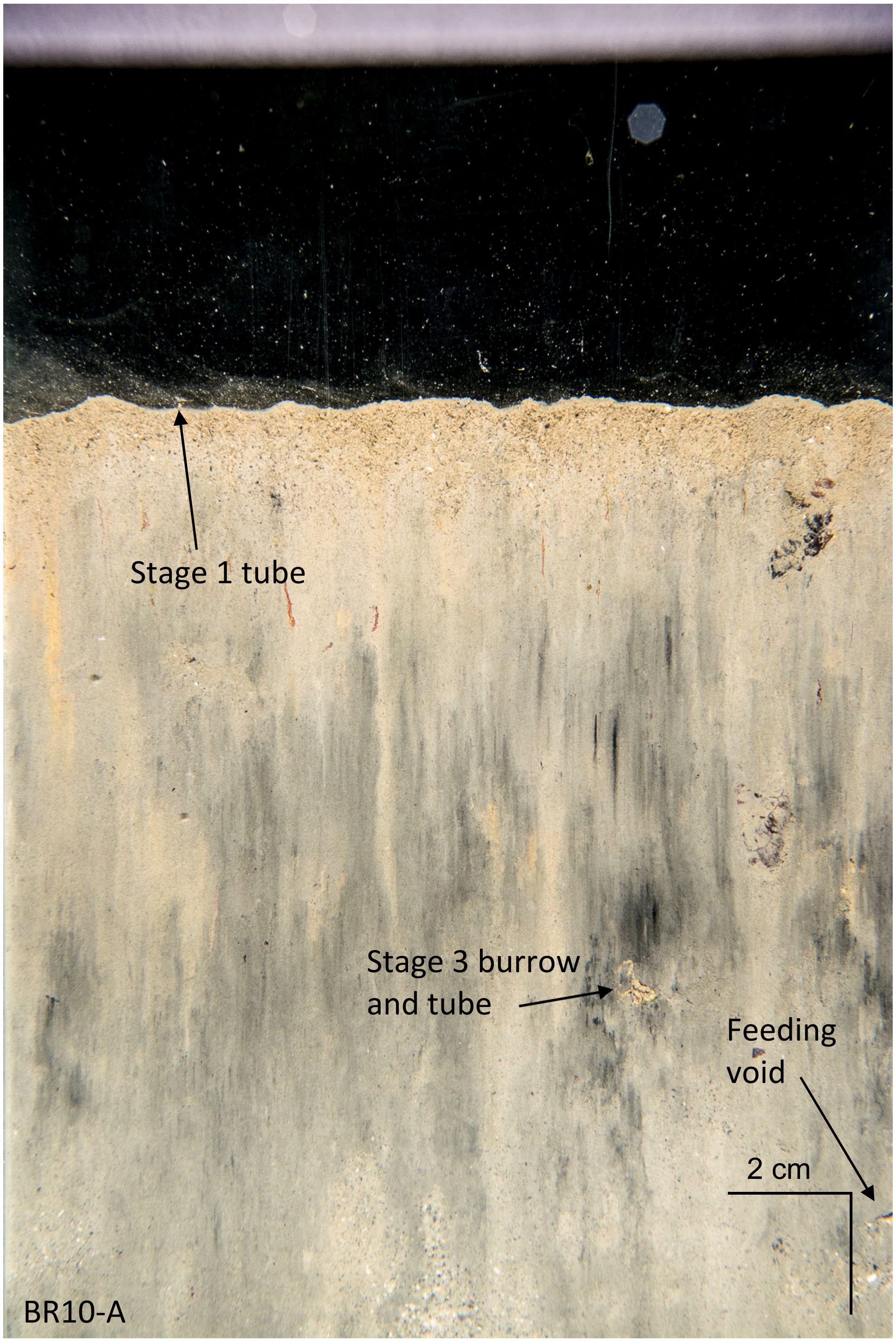


Figure 3-11. Profile image from Station BR10 with evidence of small tube-building Stage 1 taxa and burrows and feeding voids indicative of Stage 3 taxa

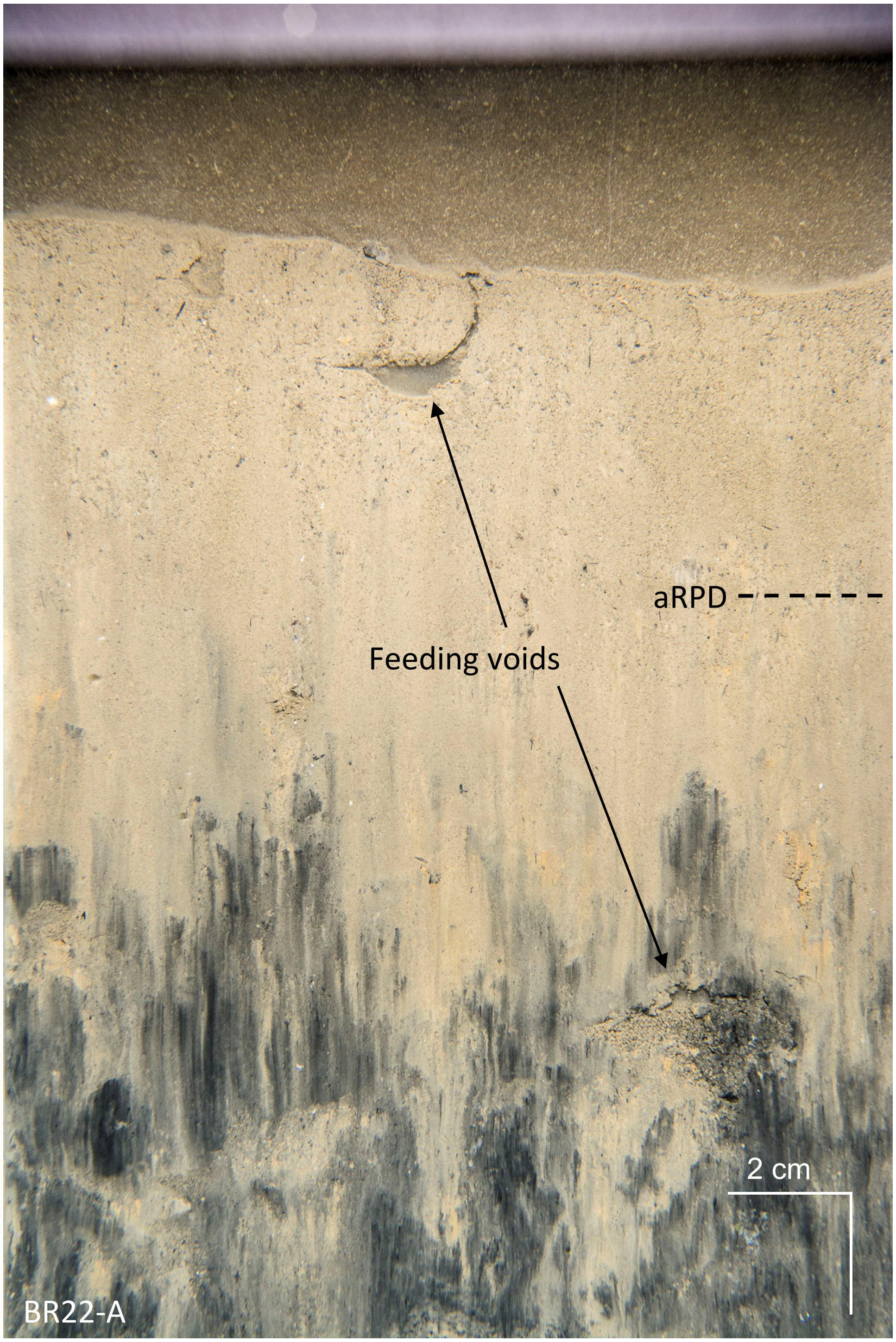


Figure 3-12. Profile image from Station BR22 with the deepest measured aRPD (4.94 cm) and large Stage 3 subsurface infauna present near the sediment-water interface and at depth

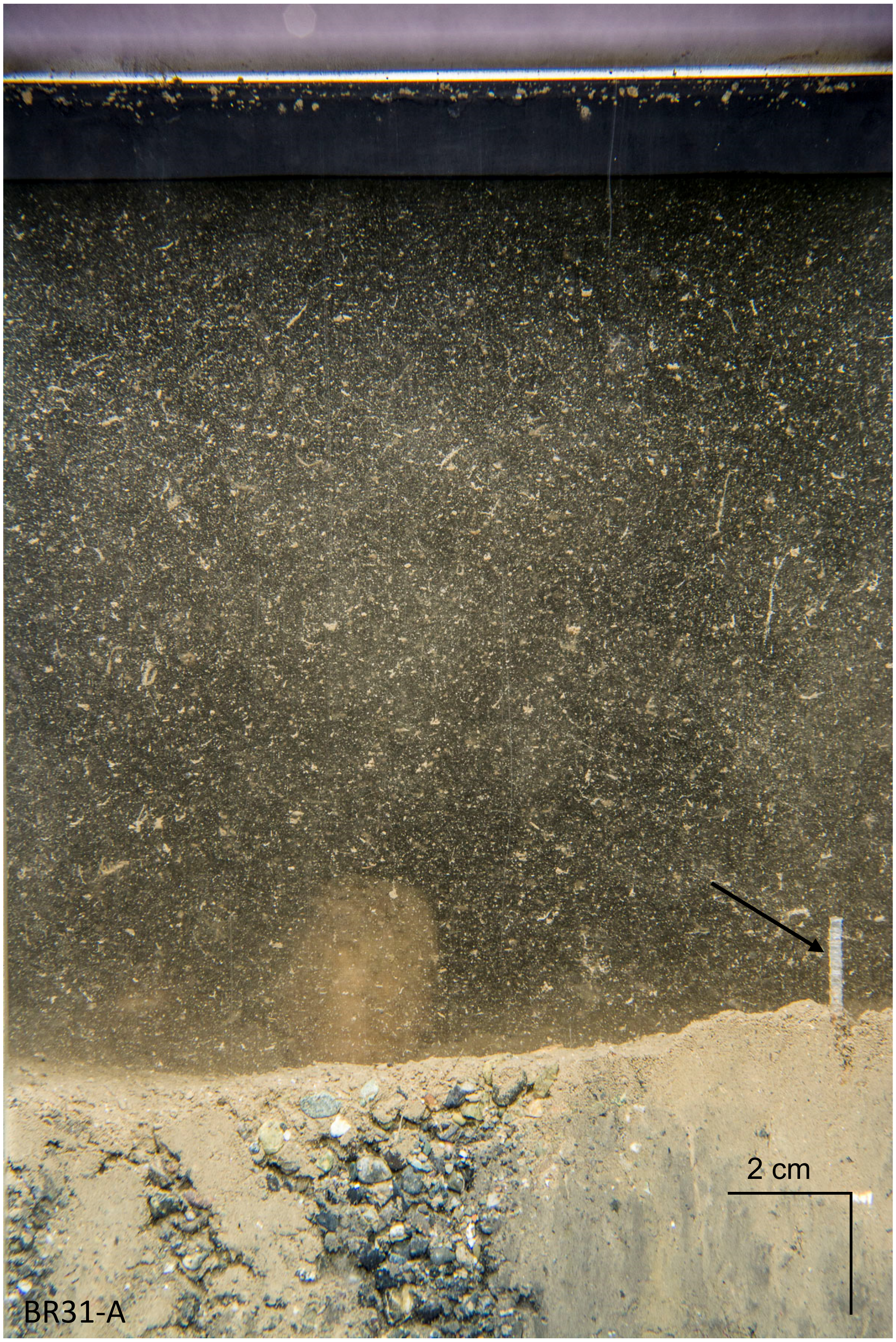


Figure 3-13. Profile image from Station BR31 showing the tube of surface-deposit feeder *Spiochaetopterus costarum* (arrow)

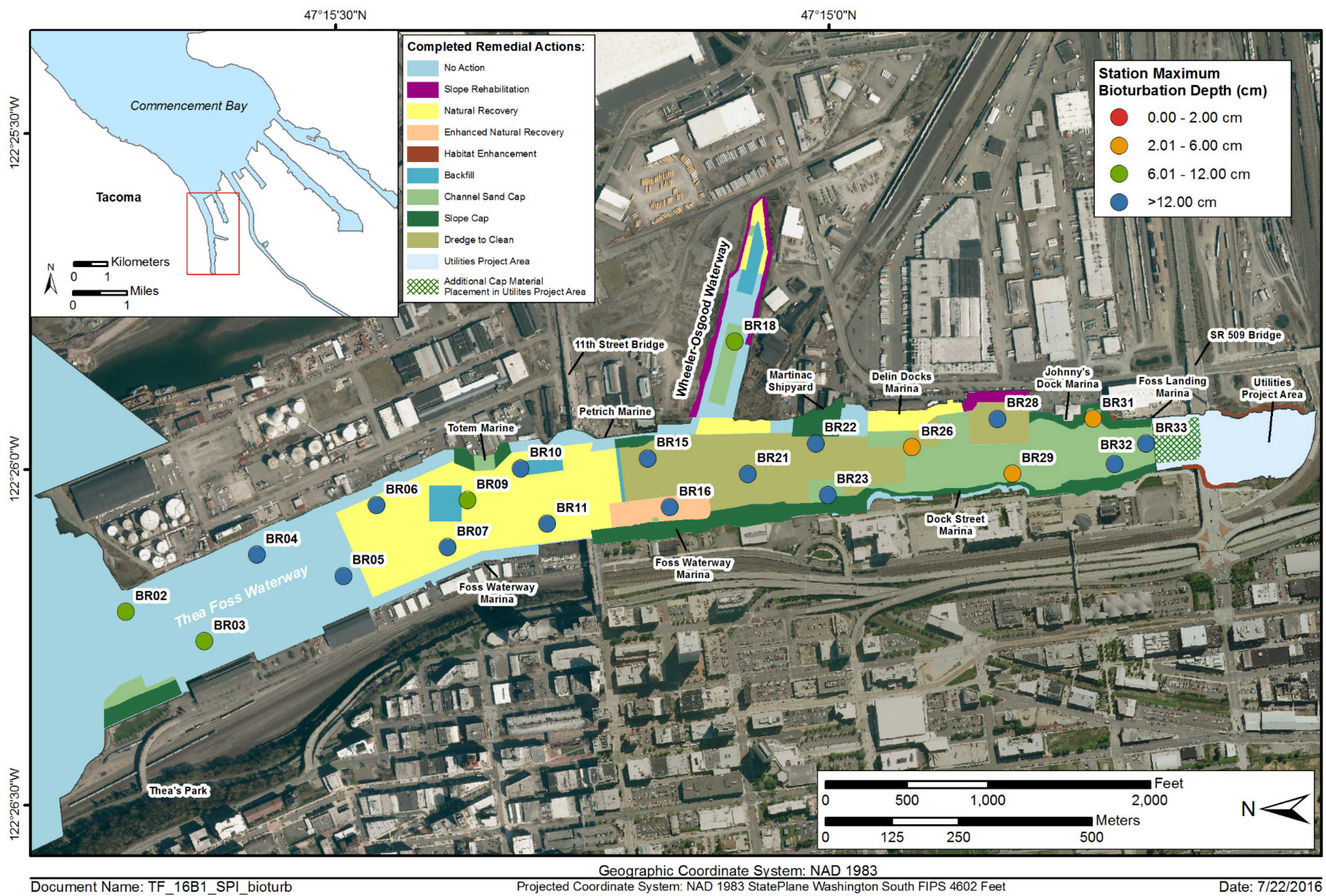


Figure 3-14. Spatial distribution of maximum bioturbation depths (cm) at stations in the Thea Foss and Wheeler-Osgood Waterways

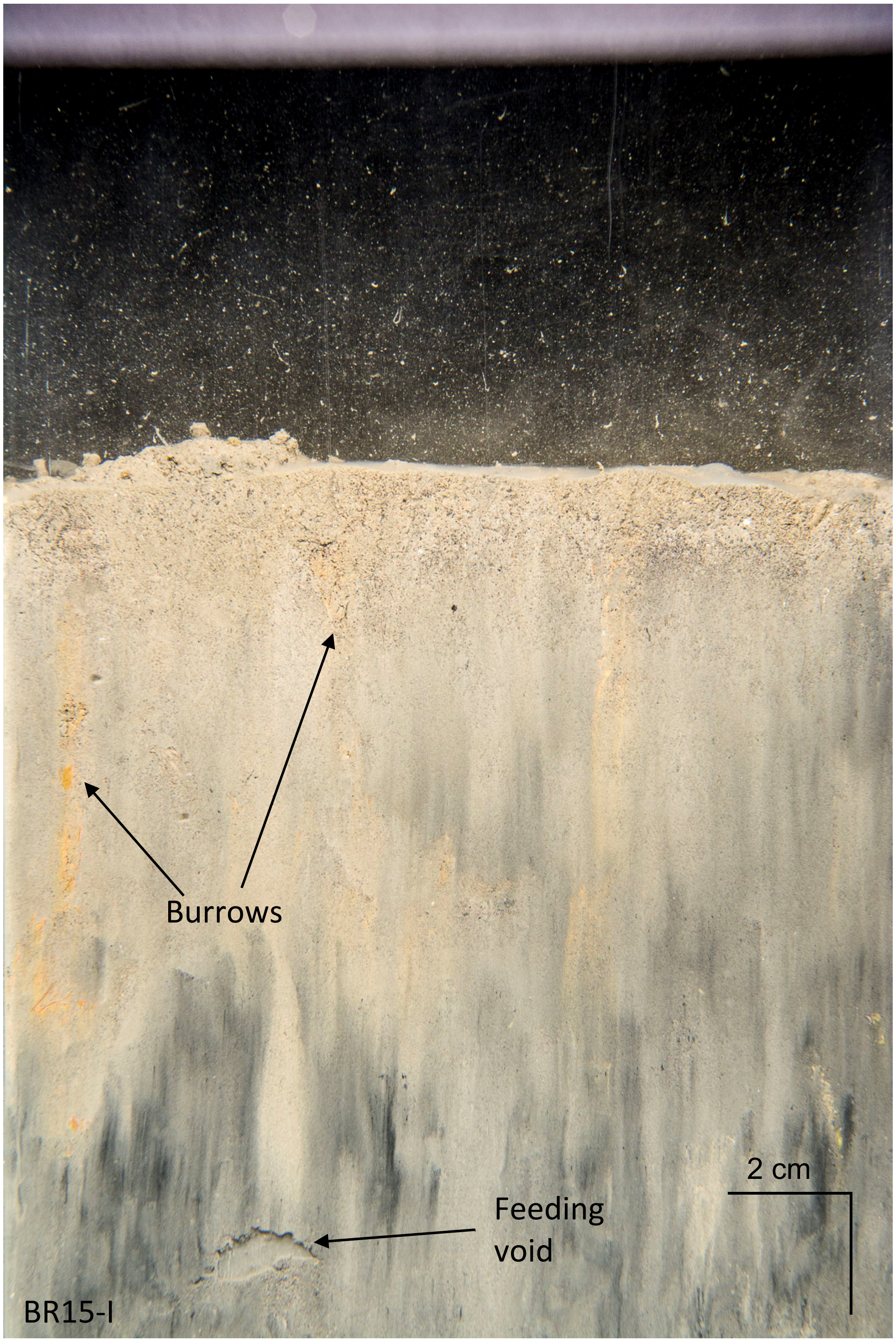


Figure 3-15. Profile image from Station BR15 depicting deep biological mixing depths with subsurface burrows and feeding void

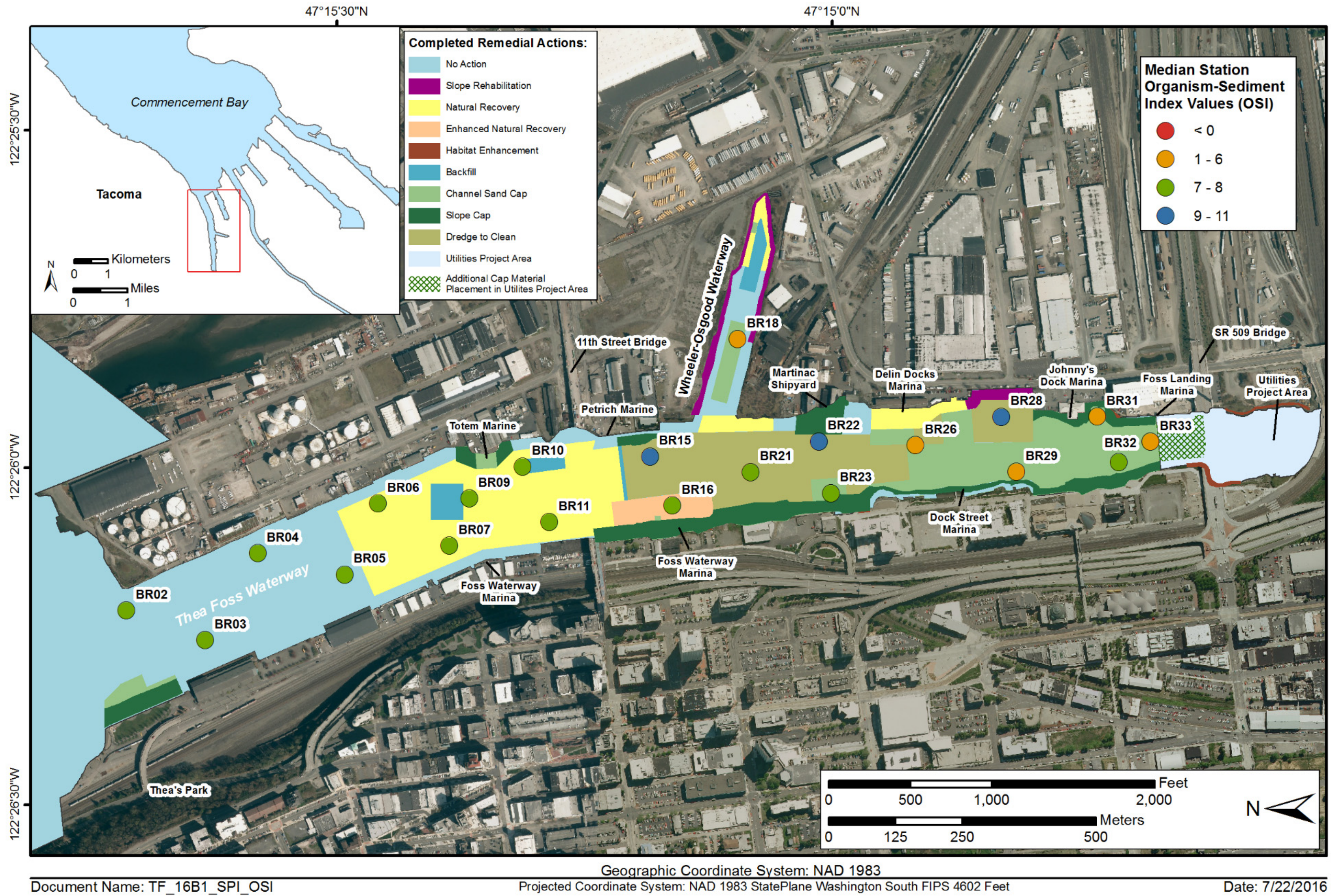


Figure 3-16. Spatial distribution of median OSI values at stations in the Thea Foss and Wheeler-Osgood Waterways

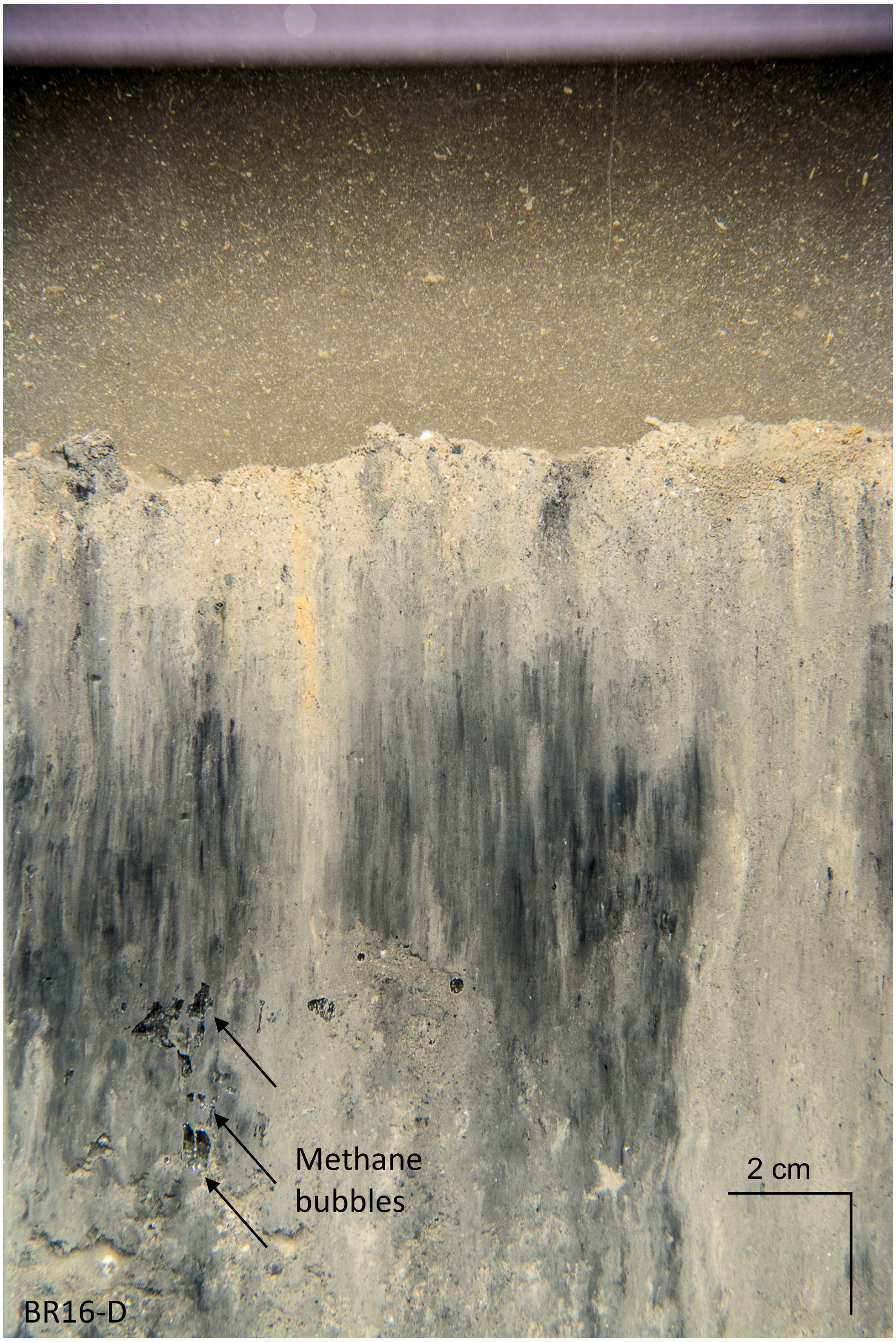


Figure 3-17. Profile image from Station BR16, which had the lowest OSI score (0) of the survey due to organically-enriched sediments with high sediment oxygen demand and numerous methane bubbles

APPENDICES

for

Year 10 Benthic Recolonization Monitoring of the Thea Foss and Wheeler-Osgood Waterways: Sediment-Profile Imaging Survey/ July 2016

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July 2016

Appendix A

SPI Station Locations

SPI Station Locations

(US State Plane NAD83, WA South Zone, Units of US Survey Feet)

Station ID	Replicate	Easting	Northing
BR02	A	1159549.430	709118.231
BR02	B	1159548.951	709115.375
BR02	C	1159548.497	709111.944
BR03	A	1159365.938	708628.426
BR03	B	1159367.819	708624.610
BR03	C	1159364.464	708627.095
BR03	D	1159366.661	708621.172
BR04	A	1159899.346	708306.130
BR04	B	1159898.398	708305.222
BR04	C	1159892.599	708306.251
BR04	D	1159893.266	708305.625
BR05	A	1159768.966	707773.149
BR05	B	1159766.930	707771.434
BR05	C	1159769.199	707771.668
BR05	D	1159768.956	707773.483
BR06	A	1160204.350	707568.256
BR06	B	1160202.065	707569.642
BR06	C	1160201.546	707568.337
BR06	D	1160201.235	707567.431
BR07	A	1159946.653	707130.177
BR07	B	1159943.936	707126.740
BR07	C	1159945.301	707127.548
BR07	D	1159942.391	707127.766
BR09	A	1160235.300	707009.344
BR09	B	1160237.705	707011.730
BR09	C	1160237.642	707008.828
BR09	D	1160235.007	707010.310
BR10	A	1160431.423	706681.790
BR10	B	1160434.511	706678.831
BR10	C	1160431.631	706681.939
BR10	D	1160431.066	706684.746
BR11	A	1160090.230	706518.262
BR11	B	1160088.969	706517.547
BR11	C	1160086.940	706520.094
BR11	D	1160088.582	706518.104
BR15	A	1160494.287	705898.463
BR15	B	1160494.942	705895.717
BR15	C	1160497.422	705899.112
BR15	D	1160495.052	705904.057
BR15	E	1160495.001	705902.142
BR15	F	1160496.344	705895.288

Station ID	Replicate	Easting	Northing
BR16	A	1160193.464	705763.062
BR16	B	1160194.276	705766.008
BR16	C	1160191.921	705763.707
BR16	D	1160192.320	705767.675
BR16	E	1160199.696	705760.083
BR16	F	1160199.791	705760.697
BR16	G	1160198.959	705764.079
BR16	H	1160199.242	705762.414
BR18	A	1161212.925	705361.461
BR18	B	1161214.123	705364.986
BR18	C	1161211.119	705364.994
BR18	D	1161208.815	705368.178
BR21	A	1160398.323	705282.606
BR21	B	1160397.738	705285.627
BR21	C	1160394.729	705281.883
BR21	D	1160397.723	705281.015
BR22	A	1160585.278	704863.598
BR22	B	1160584.872	704866.200
BR22	C	1160589.817	704863.837
BR22	D	1160585.427	704869.229
BR23	A	1160265.234	704789.145
BR23	B	1160267.931	704790.382
BR23	C	1160267.130	704793.972
BR23	D	1160268.240	704794.367
BR26	A	1160563.144	704270.011
BR26	B	1160562.088	704271.536
BR26	C	1160561.113	704274.433
BR26	D	1160560.220	704276.558
BR28	A	1160736.563	703743.407
BR28	B	1160735.185	703741.992
BR28	C	1160733.470	703740.602
BR28	D	1160732.277	703740.375
BR29	A	1160399.965	703652.055
BR29	B	1160404.920	703656.317
BR29	C	1160403.608	703649.776
BR29	D	1160401.891	703650.289
BR31	A	1160738.092	703155.966
BR31	B	1160736.687	703155.928
BR31	C	1160739.348	703154.656
BR31	D	1160739.034	703157.018
BR32	A	1160459.532	703022.536
BR32	B	1160456.385	703025.263
BR32	C	1160453.358	703024.323
BR32	D	1160457.129	703017.950
BR33	A	1160583.256	702829.646

Station ID	Replicate	Easting	Northing
BR33	B	1160584.583	702834.367
BR33	C	1160586.373	702839.608
BR33	D	1160583.624	702828.201
BR33	E	1160584.096	702821.614
BR33	F	1160583.802	702825.150
BR15	G	1160492.971	705899.230
BR15	H	1160491.963	705897.659
BR15	I	1160497.055	705898.177
BR02	D	1159547.804	709111.739
BR02	E	1159549.176	709113.418
BR02	F	1159548.107	709111.969
BR02	G	1159552.371	709122.717

Appendix B

Sediment-Profile Image Analysis Results

Note:

IND = Indeterminate

Successional Stage: "on" indicates one Stage is found on top of another Stage (i.e., 1 on 3)

"->" indicates one Stage is progressing to another Stage (i.e., 2 ->3)

Grain Size: "/" indicates layer of one phi size range over another

Station ID	Replicate	SPI Date	SPI Time	Local Date	Local Time	Depth (m)	Stops (inches)	Weights per side	Calibration Constant	Grain Size Major Mode (phi)	Grain Size Minimum (phi)	Grain Size Maximum (phi)	Grain Size Range	Penetration Mean (cm)	Boundary Roughness (cm)	Boundary Roughness Type	aRPD > Pen	Mean aRPD (cm)	Mud Clast Number	Mud Clast State	Methane?	Low DO?
BR-02	D	7/2/2016	1:07:39	7/1/2016	18:07:39	42.9	14	5	14.51	4-3/>4	>4	1	>4 to 1	11.19	1.05	Biological	FALSE	1.61	0	-	No	No
BR-02	E	7/2/2016	1:08:51	7/1/2016	18:08:51	42.9	14	5	14.51	4-3/>4	>4	3	>4 to 3	11.34	1.07	Biological	FALSE	1.63	0	-	No	No
BR-02	F	7/2/2016	1:10:10	7/1/2016	18:10:10	42.9	14	5	14.51	4-3/>4	>4	3	>4 to 3	11.88	0.96	Biological	FALSE	1.96	3	ox	No	No
BR-03	A	7/1/2016	18:55:52	7/1/2016	11:55:52	35.4	15	3	14.51	4-3/>4	>4	2	>4 to 2	9.68	0.52	Biological	FALSE	1.36	0	-	No	No
BR-03	B	7/1/2016	18:56:50	7/1/2016	11:56:50	35.4	15	3	14.51	4-3/>4	>4	2	>4 to 2	11.40	1.86	Biological	FALSE	1.74	0	-	No	No
BR-03	C	7/1/2016	18:57:49	7/1/2016	11:57:49	35.3	15	3	14.51	4-3/>4	>4	1	>4 to 1	9.85	0.87	Biological	FALSE	1.28	0	-	No	No
BR-04	A	7/1/2016	19:06:59	7/1/2016	12:06:59	30.9	15	3	14.51	4-3/>4	>4	3	>4 to 3	11.70	1.22	Biological	FALSE	1.72	0	-	No	No
BR-04	C	7/1/2016	19:09:09	7/1/2016	12:09:09	30.9	15	3	14.51	4-3/>4	>4	2	>4 to 2	12.85	1.22	Biological	FALSE	1.85	0	-	No	No
BR-04	D	7/1/2016	19:10:58	7/1/2016	12:10:58	30.9	15	3	14.51	4-3/>4	>4	2	>4 to 2	11.65	1.02	Biological	FALSE	1.27	0	-	No	No
BR-05	A	7/1/2016	19:22:12	7/1/2016	12:22:12	35.4	15	3	14.51	4-3/>4	>4	3	>4 to 3	15.36	0.44	Biological	FALSE	1.86	0	-	No	No
BR-05	B	7/1/2016	19:23:06	7/1/2016	12:23:06	35.4	15	3	14.51	4-3/>4	>4	2	>4 to 2	14.69	1.16	Biological	FALSE	1.56	0	-	No	No
BR-05	C	7/1/2016	19:23:55	7/1/2016	12:23:55	35.4	15	3	14.51	4-3/>4	>4	2	>4 to 2	14.70	0.81	Biological	FALSE	1.21	0	-	No	No
BR-06	A	7/1/2016	19:32:37	7/1/2016	12:32:37	37.1	15	3	14.51	4-3/>4	>4	3	>4 to 3	16.14	0.38	Biological	FALSE	1.62	0	-	No	No
BR-06	B	7/1/2016	19:33:26	7/1/2016	12:33:26	37.1	15	3	14.51	>4	>4	3	>4 to 3	18.43	0.85	Biological	FALSE	1.42	3	red	No	No
BR-06	C	7/1/2016	19:34:14	7/1/2016	12:34:14	37.1	15	3	14.51	>4	>4	3	>4 to 3	17.09	0.61	Biological	FALSE	1.06	3	red	No	No

Station ID	Replicate	SPI Date	SPI Time	Local Date	Local Time	Depth (m)	Stops (inches)	Weights per side	Calibration Constant	Grain Size Major Mode (phi)	Grain Size Minimum (phi)	Grain Size Maximum (phi)	Grain Size Range	Penetration Mean (cm)	Boundary Roughness (cm)	Boundary Roughness Type	aRPD > Pen	Mean aRPD (cm)	Mud Clast Number	Mud Clast State	Methane?	Low DO?
BR-07	A	7/1/2016	19:45:23	7/1/2016	12:45:23	36.1	15	3	14.51	>4	>4	3	>4 to 3	16.86	0.70	Biological	FALSE	1.06	0	-	No	No
BR-07	B	7/1/2016	19:47:31	7/1/2016	12:47:31	36.1	15	3	14.51	>4	>4	3	>4 to 3	17.70	0.76	Biological	FALSE	1.01	0	-	No	No
BR-07	C	7/1/2016	19:48:27	7/1/2016	12:48:27	36.1	15	3	14.51	>4	>4	1	>4 to 1	17.98	0.61	Biological	FALSE	0.91	1	ox	No	No
BR-09	A	7/1/2016	20:12:50	7/1/2016	13:12:50	36.8	14	1	14.51	4-3/>4	>4	3	>4 to 3	8.23	0.83	Biological	FALSE	1.10	0	-	No	No
BR-09	B	7/1/2016	20:13:47	7/1/2016	13:13:47	36.7	14	1	14.51	4-3/>4	>4	2	>4 to 2	9.64	0.89	Biological	FALSE	0.79	6	red/ox	No	No
BR-09	C	7/1/2016	20:14:38	7/1/2016	13:14:38	36.8	14	1	14.51	4-3/>4	>4	3	>4 to 3	9.77	0.90	Biological	FALSE	0.90	5	red/ox	No	No
BR-10	A	7/1/2016	20:21:37	7/1/2016	13:21:37	35.8	15	3	14.51	4-3/>4	>4	3	>4 to 3	15.21	0.49	Biological	FALSE	1.00	0	-	No	No
BR-10	C	7/1/2016	20:24:31	7/1/2016	13:24:31	37.1	15	3	14.51	4-3/>4	>4	2	>4 to 2	15.13	0.46	Biological	FALSE	0.83	0	-	No	No
BR-10	D	7/1/2016	20:25:34	7/1/2016	13:25:34	37.1	15	3	14.51	4-3/>4	>4	2	>4 to 2	16.51	0.69	Biological	FALSE	1.19	0	-	No	No
BR-11	A	7/1/2016	20:33:02	7/1/2016	13:33:02	37.5	14	3	14.51	>4	>4	3	>4 to 3	15.66	1.15	Biological	FALSE	0.94	0	-	No	No
BR-11	B	7/1/2016	20:33:55	7/1/2016	13:33:55	37.5	14	3	14.51	>4	>4	3	>4 to 3	15.60	0.94	Biological	FALSE	0.96	0	-	No	No
BR-11	C	7/1/2016	20:34:49	7/1/2016	13:34:49	37.4	14	3	14.51	>4	>4	2	>4 to 2	13.51	2.58	Biological	FALSE	0.73	0	-	No	Yes
BR-15	G	7/2/2016	0:49:58	7/1/2016	17:49:58	45.8	14	5	14.51	4-3/>4	>4	3	>4 to 3	14.23	1.68	Biological	FALSE	2.70	0	-	No	No

Station ID	Replicate	SPI Date	SPI Time	Local Date	Local Time	Depth (m)	Stops (inches)	Weights per side	Calibration Constant	Grain Size Major Mode (phi)	Grain Size Minimum (phi)	Grain Size Maximum (phi)	Grain Size Range	Penetration Mean (cm)	Boundary Roughness (cm)	Boundary Roughness Type	aRPD > Pen	Mean aRPD (cm)	Mud Clast Number	Mud Clast State	Methane?	Low DO?
BR-15	H	7/2/2016	0:50:58	7/1/2016	17:50:58	45.8	14	5	14.51	4-3/>4	>4	3	>4 to 3	15.88	1.81	Biological	FALSE	2.74	0	-	No	No
BR-15	I	7/2/2016	0:51:58	7/1/2016	17:51:58	45.8	14	5	14.51	4-3/>4	>4	3	>4 to 3	13.96	0.65	Biological	FALSE	1.15	5	ox	No	No
BR-16	A	7/1/2016	21:44:15	7/1/2016	14:44:15	34.3	14	3	14.51	>4	>4	3	>4 to 3	14.56	0.74	Biological	FALSE	0.80	0	-	No	No
BR-16	B	7/1/2016	21:45:11	7/1/2016	14:45:11	34.3	14	3	14.51	>4	>4	3	>4 to 3	15.31	1.13	Biological	FALSE	0.81	0	-	No	No
BR-16	D	7/1/2016	21:48:59	7/1/2016	14:48:59	34.3	14	3	14.51	>4	>4	2	>4 to 2	14.50	1.18	Biological	FALSE	0.73	0	-	Yes	Yes
BR-18	A	7/1/2016	22:03:53	7/1/2016	15:03:53	35	16	5	14.51	4-3/>4	>4	2	>4 to 2	14.52	1.42	Biological	FALSE	1.58	0	-	No	No
BR-18	B	7/1/2016	22:04:48	7/1/2016	15:04:48	35	16	5	14.51	4-3/>4	>4	1	>4 to 1	15.14	1.80	Biological	FALSE	0.88	0	-	No	No
BR-18	C	7/1/2016	22:05:39	7/1/2016	15:05:39	35	16	5	14.51	4-3/>4	>4	1	>4 to 1	17.34	1.02	Biological	FALSE	1.23	0	-	No	No
BR-21	A	7/1/2016	22:19:04	7/1/2016	15:19:04	45.7	14	3	14.51	>4	>4	3	>4 to 3	13.10	0.54	Biological	FALSE	1.05	0	-	No	No
BR-21	B	7/1/2016	22:20:10	7/1/2016	15:20:10	45.7	14	3	14.51	>4	>4	3	>4 to 3	14.81	1.00	Biological	FALSE	0.85	1	red	No	No
BR-21	C	7/1/2016	22:21:03	7/1/2016	15:21:03	45.7	14	3	14.51	>4	>4	3	>4 to 3	15.20	1.04	Biological	FALSE	0.83	2	red	No	No
BR-22	A	7/1/2016	22:28:14	7/1/2016	15:28:14	39.1	14	3	14.51	4-3/>4	>4	3	>4 to 3	17.52	1.28	Biological	FALSE	4.94	1	red	No	No
BR-22	C	7/1/2016	22:30:20	7/1/2016	15:30:20	37	14	3	14.51	4-3/>4	>4	2	>4 to 2	18.07	0.94	Biological	FALSE	2.29	0	-	No	No

Station ID	Replicate	SPI Date	SPI Time	Local Date	Local Time	Depth (m)	Stops (inches)	Weights per side	Calibration Constant	Grain Size Major Mode (phi)	Grain Size Minimum (phi)	Grain Size Maximum (phi)	Grain Size Range	Penetration Mean (cm)	Boundary Roughness (cm)	Boundary Roughness Type	aRPD > Pen	Mean aRPD (cm)	Mud Clast Number	Mud Clast State	Methane?	Low DO?
BR-22	D	7/1/2016	22:31:26	7/1/2016	15:31:26	39.8	14	3	14.51	4-3/>4	>4	3	>4 to 3	17.47	1.53	Biological	FALSE	2.22	0	-	No	No
BR-23	B	7/1/2016	22:39:27	7/1/2016	15:39:27	36.6	14	3	14.51	>4	>4	3	>4 to 3	15.72	0.96	Biological	FALSE	0.73	0	-	No	No
BR-23	C	7/1/2016	22:42:19	7/1/2016	15:42:19	36.6	14	3	14.51	>4	>4	2	>4 to 2	16.86	1.48	Biological	FALSE	1.40	0	-	No	No
BR-23	D	7/1/2016	22:43:54	7/1/2016	15:43:54	36.6	14	3	14.51	>4	>4	2	>4 to 2	16.31	1.13	Biological	FALSE	1.23	2	ox	No	No
BR-26	A	7/1/2016	22:54:57	7/1/2016	15:54:57	30.1	14	3	14.51	4-3	>4	1	>4 to 1	5.66	0.65	Biological	FALSE	1.30	0	-	No	No
BR-26	B	7/1/2016	22:55:39	7/1/2016	15:55:39	29.8	14	3	14.51	4-3	>4	1	>4 to 1	6.72	0.91	Biological	FALSE	1.13	3	ox	No	No
BR-26	C	7/1/2016	22:56:30	7/1/2016	15:56:30	29.9	14	3	14.51	4-3	>4	1	>4 to 1	6.05	0.73	Biological	FALSE	0.83	4	ox	No	No
BR-28	A	7/1/2016	23:13:36	7/1/2016	16:13:36	31	14	3	14.51	4-3/>4	>4	3	>4 to 3	16.10	2.38	Biological	FALSE	3.62	0	-	No	No
BR-28	C	7/1/2016	23:15:38	7/1/2016	16:15:38	31	14	3	14.51	4-3/>4	>4	3	>4 to 3	15.76	0.80	Biological	FALSE	4.08	2	ox	No	No
BR-28	D	7/1/2016	23:16:29	7/1/2016	16:16:29	31	14	3	14.51	4-3>4	>4	3	>4 to 3	15.81	2.18	Biological	FALSE	2.93	1	ox	No	No
BR-29	A	7/1/2016	23:24:36	7/1/2016	16:24:36	29.1	14	5	14.51	4-3	>4	1	>4 to 1	4.80	1.45	Biological	FALSE	1.16	0	-	No	No
BR-29	B	7/1/2016	23:25:55	7/1/2016	16:25:55	29.1	14	5	14.51	>4	>4	2	>4 to 2	6.00	1.39	Biological	FALSE	0.86	0	-	No	No
BR-29	C	7/1/2016	23:27:01	7/1/2016	16:27:01	23.4	14	5	14.51	4-3	>4	2	>4 to 2	5.21	0.62	Biological	FALSE	1.06	0	-	No	No

Station ID	Replicate	SPI Date	SPI Time	Local Date	Local Time	Depth (m)	Stops (inches)	Weights per side	Calibration Constant	Grain Size Major Mode (phi)	Grain Size Minimum (phi)	Grain Size Maximum (phi)	Grain Size Range	Penetration Mean (cm)	Boundary Roughness (cm)	Boundary Roughness Type	aRPD > Pen	Mean aRPD (cm)	Mud Clast Number	Mud Clast State	Methane?	Low DO?
BR-31	A	7/1/2016	23:36:19	7/1/2016	16:36:19	21.3	14	5	14.51	-2 - -6/>4	>4	-6	>4 to -6	4.43	2.10	Biological	FALSE	1.17	0	-	No	No
BR-31	B	7/1/2016	23:37:24	7/1/2016	16:37:24	21.3	14	5	14.51	4-3/>4	>4	0	>4 to 0	6.55	0.71	Biological	FALSE	1.02	0	-	No	No
BR-31	C	7/1/2016	23:38:24	7/1/2016	16:38:24	21.3	14	5	14.51	4-3/>4	>4	-2	>4 to -2	6.18	0.92	Biological	FALSE	0.88	0	-	No	No
BR-32	A	7/1/2016	23:54:07	7/1/2016	16:54:07	23	14	5	14.51	>4	>4	0	>4 to 0	16.30	1.98	Biological	FALSE	1.14	0	-	No	No
BR-32	B	7/1/2016	23:55:06	7/1/2016	16:55:06	23	14	5	14.51	>4	>4	1	>4 to 1	15.16	0.87	Biological	FALSE	0.69	0	-	No	No
BR-32	D	7/1/2016	23:58:13	7/1/2016	16:58:13	22.9	14	5	14.51	4-3/>4	>4	2	>4 to 2	16.52	1.07	Biological	FALSE	1.80	0	-	No	No
BR-33	D	7/2/2016	0:18:09	7/1/2016	17:18:09	31.1	14	5	14.51	>4	>4	2	>4 to 2	11.41	1.91	Biological	FALSE	0.79	0	-	No	Yes
BR-33	E	7/2/2016	0:20:49	7/1/2016	17:20:49	31.1	14	5	14.51	>4	>4	3	>4 to 3	12.44	3.22	Biological	FALSE	0.95	0	-	No	No
BR-33	F	7/2/2016	0:22:14	7/1/2016	17:22:14	31.1	14	5	14.51	>4	>4	3	>4 to 3	13.82	1.48	Biological	FALSE	1.55	0	-	No	No

Station ID	Replicate	# of Feeding Voids	Void Minimum Depth (cm)	Void Maximum Depth (cm)	Maximum Bioturbation Depth (cm)	Successional Stage	Comment	OSI
BR-02	D	1	1.34	1.85	9.88	1 on 3	Silty very fine sand over silt/clay. Large clump of green algae present at SWI. Some worms visible in sediment. Feeding voids throughout image; one large one likely that has left an orange streak from prism penetration.	8
BR-02	E	1	10.62	10.92	10.92	1 on 3	Silty very fine sand over silt/clay. Green algae present at SWI. Sediment cloud fills water column. Worms and evidence of deeper burrowing visible throughout image. Void at depth.	8
BR-02	F	1	10.43	10.68	10.68	2 on 3	Silty vey fine sand over silt/clay. Some green algae present in background of SWI. Some small tubes and oxidized mud clasts visible at SWI. Stage 2 tubes and oxidized mud clasts visible at SWI. Worms and burrows visible below aRPD and at depth. Filled feeding void at depth.	8
BR-03	A	1	8.74	9.17	9.86	3	Silty very fine sand over silt/clay. Cloud of sediment suspended in water column. Small burrows within and below aRPD. Worms visible in sediment below aRPD layer.	7
BR-03	B	1	2.79	3.42	11.64	3	Silty very fine sand over silt/clay. Sediment cloud in water column. Small burrows within and below aRPD. Open void just below aRPD. Worms visible throughout sediment.	8
BR-03	C	0			9.37	3	Silty very fine sand over silt/clay. Fecal pellets at SWI on left. Possible tube at SWI. Small burrows within and below aRPD. A few worms visible deep in sediment.	7
BR-04	A	3	2.61	6.27	11.61	1 on 3	Fine silt/clay. Small burrows in aRPD. Infilled feeding voids present beneath aRPD.	8
BR-04	C	3	3.60	11.11	12.19	1 on 3	Fine silt/clay. Cloud of sediment in water column making it difficult to determine what is resting on top of sediment. Appears to possibly be a mussel shell? Small to medium burrows and infilled voids throughout sediment. A few visible worms within sediment.	8
BR-04	D	1	10.39	10.62	11.46	1 on 3	Fine silt/clay. Worms visible throughout sediment beneath aRPD layer. Small void at depth	7
BR-05	A	1	10.13	10.62	13.06	1 on 3	Fine silt/clay, with some coarser grains near SWI. Small tubes present at SWI. Small burrows within and below aRPD. Infilled void deep in sediment. Worms visible in sediment.	8
BR-05	B	0			11.09	3	Fine silt/clay. Pocket of dark, coarse sediment present near SWI. Small worms present throughout in sediment.	8
BR-05	C	2	6.41	10.36	12.10	3	Fine silt/clay. Mud clasts from camera frame at SWI. Worms visible beneath aRPD. Infilled and open voids beneath aRPD.	7
BR-06	A	1	14.40	14.64	14.64	1 on 3	Silt/clay with a thin layer of silty, fine sand at SWI. Worms visible in burrows and closed in burrows visible beneath aRPD. Lumen of a few burrows transected by camera, oxidized particles visible within. One infilled voids at depth.	8
BR-06	B	2	9.49	17.18	18.25	3	Silt/clay. Reduced mud clasts and some large clumps of mud rest at SWI. Filled voids.	7
BR-06	C	3	4.21	12.94	14.22	3	Silt/clay. Some reduced mud clasts and sed at SWI. Worms visible in burrows. Both open and closed voids beneath aRPD.	7

Station ID	Replicate	# of Feeding Voids	Void Minimum Depth (cm)	Void Maximum Depth (cm)	Maximum Bioturbation Depth (cm)	Successional Stage	Comment	OSI
BR-07	A	3	5.74	15.35	16.48	2 on 3	Silt/clay. Small tubes visible at SWI. Worms visible in burrows. Burrows throughout sediment including near SWI and at depth. Open and infilled voids beneath aRPD.	7
BR-07	B	3	1.64	15.06	17.01	1 on 3	Silt/clay. Some sed on surface, possibly from camera wiper blade. Burrows present at aRPD and descending. Many burrows have worms visibly present. A few open voids at depth.	7
BR-07	C	5	4.57	17.28	17.28	3	Silt/clay. Some larger grains near SWI. Small oxidized mud clast. Burrows present beneath aRPD. Many burrows have worms visibly present; one with lumen transected and oxidized sed within. A few closed voids at depth.	7
BR-09	A	3	1.55	5.44	5.92	1 on 3	Silt/clay with a thin layer of silty, fine sand at SWI. Two very large burrows with white, wispy material within them. Many smaller burrows throughout sediment, some contain worms. Two open voids below aRPD.	7
BR-09	B	0			8.95	1 on 3	Silt/clay with a thin layer of silty, fine sand at SWI. Some possible shell fragments in top layer of sediment. 4 reduced, 2 oxidized mud clasts at SWI. Large, filled in burrow just below aRPD. Burrow with visible worm at depth.	7
BR-09	C	1	4.31	4.61	9.11	3	Silt/clay with a thin layer of silty, fine sand at SWI. 4 reduced, 1 oxidized mud clast at SWI. Filled burrow near aRPD. Open void beneath aRPD and worm present in a burrow at depth.	7
BR-10	A	1	13.21	13.36	14.23	1 on 3	Silt/clay with a thin layer of silty, fine sand at SWI. A couple open burrows beneath aRPD. Open void at depth just in frame on right. Many burrows containing worms present just below aRPD. Some coarse sediment at depth.	7
BR-10	C	2	5.22	5.73	8.14	1 on 3	Silt/clay with a layer of silty, fine sand containing some larger grain sizes at SWI. An open and a closed void beneath aRPD. Some burrows with visible worms beneath voids.	7
BR-10	D	2	10.49	11.94	12.80	1 on 3	Silt/clay with a layer of silty, fine sand containing some larger grain sizes at SWI. A very large half-filled void next to a filled void. Some burrows just below aRPD and worms visible in a few.	7
BR-11	A	2	4.98	10.39	13.51	2 on 3	Silt/clay with some silty, fine sand at SWI. Some fecal pellets at SWI. Many burrows with worms visible beneath aRPD. Filled voids at depth.	7
BR-11	B	2	14.58	15.41	15.41	3	Silt/clay with some silty, fine sand at SWI. Fecal pellets visible in aRPD. Many burrows with worms visible beneath aRPD. Large, open void at depth.	7
BR-11	C	2	10.23	10.97	12.52	1 on 3	Silt/clay with some more coarse grained sediment mixed near the SWI. Patchy aRPD interspersed with patches of gray low oxy demand sed at SWI. Burrows with visible worms throughout. An open and a closed void at depth.	2
BR-15	G	3	3.91	7.08	11.21	2 on 3	Silt/clay with fine sand near the SWI. Burrows begin within aRPD and continue to depth, many containing worms. One void connected to surface mound by burrow	9

Station ID	Replicate	# of Feeding Voids	Void Minimum Depth (cm)	Void Maximum Depth (cm)	Maximum Bioturbation Depth (cm)	Successional Stage	Comment	OSI
BR-15	H	0			11.93	1 on 3	Silt/clay with fine sand near the SWI. Some small tubes visible at SWI. Burrows visible beneath aRPD. Fecal pellets in ~1 cm below SWI at left. Burrow containing a worm near open void.	9
BR-15	I	1	12.30	13.10	13.10	1 on 3	Silt/clay with fine sand near the SWI. Small tubes and a large tube visible at SWI. Large tube has associated mud clasts. Burrows beneath aRPD. Large, open void at depth.	7
BR-16	A	3	2.42	12.96	14.54	1 on 3	Silt/clay with some coarser grains near SWI. Several capitellid worms below aRPD. Dark reduced sediment from mid-depth, with mixed texture at depth, chaotic texture with some appearance of former voids	7
BR-16	B	1	12.78	12.89	15.04	2 on 3	Silt/clay. A few burrows and small worms below aRPD. Possible small bivalve just below SWI. Dark reduced sediment from mid-depth, with mixed texture at depth, chaotic texture with some appearance of former voids. One burrow at depth with a visible worm. Infilled void at depth near infilled burrows.	7
BR-16	D	2	10.96	13.42	13.42	1 on 3	Silt/clay w some coarser grains near SWI as well as some more coarse grain sediment pockets at SWI. A couple tubes visible at SWI. A few burrows near aRPD. Dark reduced sediment from mid-depth, with mixed texture at depth, chaotic texture with some appearance of former voids. Two voids at left with some fauna visible. Over a dozen methane bubbles at depth.	0
BR-18	A	0			8.23	2 -> 3	Silt/clay with fine sand and some intermixed coarse grain sediment at SWI. Few capitellids at depth.	7
BR-18	B	0			5.45	2 -> 3	Silt/clay with large grain sediment at SWI. Relict aRPD	6
BR-18	C	0			9.81	2 -> 3	Silt/clay with large grain sediment at SWI. Relict aRPD	6
BR-21	A	1	9.75	10.08	11.54	1 on 3	Silt/clay. Burrows with worms begin just beneath SWI and continue throughout image. One filled void at depth.	7
BR-21	B	2	5.63	6.83	14.20	1 on 3	Silt/clay. One reduced mud clast. A couple crushed voids below aRPD. Small burrows in aRPD. Burrows, many with visible worms, begin beneath aRPD and continue to depth.	7
BR-21	C	2	6.08	14.79	14.79	1 on 3	Silt/clay. Burrows begin near SWI and continue to depth, many containing visible worms. An open void beneath aRPD as well as another at depth.	7
BR-22	A	4	1.38	13.23	16.03	3	Silt/clay with fine sand near SWI. Burrows at SWI with large, open void just beneath SWI. A partially filled void below aRPD and an open void at depth. Burrows throughout profile, many containing visible worms.	11
BR-22	C	3	6.86	11.11	16.89	3	Silt/clay with layer of fine sand and intermixed coarser grain sediment near SWI. A partially filled void below aRPD with many infilled burrows beneath aRPD continuing to depth.	9

Station ID	Replicate	# of Feeding Voids	Void Minimum Depth (cm)	Void Maximum Depth (cm)	Maximum Bioturbation Depth (cm)	Successional Stage	Comment	OSI
BR-22	D	2	3.64	15.00	15.79	1 on 3	Silt/clay with layer of fine sand near SWI. An open void beneath aRPD. Infilled burrows beginning beneath aRPD and continuing to depth. A partially filled void at depth.	8
BR-23	B	3	5.30	14.97	15.47	3	Silt/clay. Some debris penetrates sediment in upper 10 cm; appears to be wood debris. Large, partially filled void present below aRPD, completely surrounded by reduced sediment, as well as a filled void and several burrows with worms visible. Large, filled burrow present at depth.	6
BR-23	C	0			7.92	1 on 3	Silt/clay containing intermixed coarser grain sediment near SWI. A tube is visible at SWI. Some burrows beneath aRPD, one containing a visible worm. Debris, appears to be woody, in upper several cm	7
BR-23	D	0			11.78	3	Silt/clay containing intermixed coarser grain sediment near SWI. Debris, appears to be woody, in upper several cm. Patch of reduced sediment just below SWI connected to burrow filled with reduced sediment. Another large burrow is partially filled at depth.	7
BR-26	A	0			5.19	2 -> 3	Silt/clay with some fine sand at SWI. Large grained sediment in one area on right. Small burrows, some containing small visible worms below aRPD.	6
BR-26	B	0			5.66	2 -> 3	Silt/clay with some fine sand containing large, coarse grained sediment at the SWI. Few small oxidized mud clasts at SWI. Large clear/white tube visible at SWI- likely Spiochaetopterus costarum. Small burrow and worms below aRPD	6
BR-26	C	0			4.61	2 -> 3	Silt/clay with some fine sand containing large, coarse grained sediment at the SWI. Small shallow burrows	6
BR-28	A	1	10.43	10.77	14.45	2 on 3	Silt/clay with a layer of fine sand at SWI. Shallow burrows just below SWI. Small bivalve just below SWI on right. Infilled void and infilled burrow at depth. Open burrows at depth, one containing a visible worm.	10
BR-28	C	5	7.96	14.32	15.66	3	Silt/clay with a layer of fine sand at SWI. Connected voids and open and filled voids at depth. Burrows in aRPD and at depth	11
BR-28	D	3	5.00	15.98	16.13	3	Silt/clay with a layer of fine sand at SWI. Small burrows visible near SWI. Void near aRPD appears to have been crushed by prism. Infilled burrows beneath aRPD with patch of reworked sed at SWI directly above. Worm visible in burrow near aRPD and below open void. A large open void and a small open void at depth.	9
BR-29	A	0			4.95	2	Silt/clay with a layer of fine sand with intermixed coarse grained sediment near SWI. Very small burrows present beneath aRPD. Shallow penetration	5
BR-29	B	0			4.73	2	Silt/clay with a layer of fine sand with intermixed coarse grained sediment near SWI. Very small burrows present beneath aRPD. Shallow penetration	5
BR-29	C	0			4.44	2	Silt/clay with a layer of fine sand with intermixed coarse grained sediment near SWI. A large, filled burrow and smaller burrows beneath aRPD. Shallow penetration.	5

Station ID	Replicate	# of Feeding Voids	Void Minimum Depth (cm)	Void Maximum Depth (cm)	Maximum Bioturbation Depth (cm)	Successional Stage	Comment	OSI
BR-31	A	0			4.11	2	Silt/clay and pebbles; pebbles begin at SWI and continue to depth in left half of picture. Layer of small fecal pellets (somewhat deteriorated) at SWI on right. Large clear/white tube visible at SWI- likely Spiochaetopterus costarum. Shallow penetration	5
BR-31	B	0			3.70	2	Silt/clay with layer of fine sand. Small burrows within aRPD, bit of small worm visible below aRPD. White fauna just visible below SWI (possibly bivalve). Shallow penetration.	5
BR-31	C	0			5.79	2	Silt/clay with layer of fine sand, area of granules and pebbles from SWI to depth at center. Bivalve just below SWI to left. Shallow penetration.	5
BR-32	A	1	14.00	14.15	15.69	2 on 3	Silt/clay with are of coarse sed just below SWI on left. Burrows in aRPD. Bivalve (?) on right. Worm below aRPD. Worm and small void at depth.	7
BR-32	B	0			7.70	2 -> 3	Silt/clay with some coarser grains below SWI. Thin layer of mixed ox/red degraded fecal pellets at SWI. One thin worm below aRPD. Evidence of some burrowing at depth	5
BR-32	D	1	6.53	10.36	15.26	3	Silt/clay with layer of fine sand. Small and medium burrows through and beneath aRPD, one thin worm visible. Large, open void beneath aRPD.	8
BR-33	D	0			7.46	2 -> 3	Silt/clay. Large clear/white tube visible at SWI- likely Spiochaetopterus costarum. Small patch of gray reduced sediment in contact with SWI at left. Small worms to medium below aRPD. Potential closed voids or burrows below aRPD.	2
BR-33	E	0			9.32	2 -> 3	Silt/clay. Invertebrate (crab or lobster). Small fish and shell fragment at SWI on right. Group of barnacles buried below layer of fine reworked sediment at left. Evidence of a large burrow that has been disturbed and partially filled near SWI at far right. Thin worm and infilled burrows exist at depth.	6
BR-33	F	0			12.78	2 -> 3	Silt/clay. Burrows through aRPD and below. Few small worms visible.	7

ATTACHMENT B

Sediment Profile Images

TF-B1-SPI-BR-02-A

TF-B1-SPI-BR-02-B

TF-B1-SPI-BR-02-C

TF-B1-SPI-BR-02-D

TF-B1-SPI-BR-02-E

TF-B1-SPI-BR-02-F

TF-B1-SPI-BR-02-G

TF-B1-SPI-BR-03-A

TF-B1-SPI-BR-03-B

TF-B1-SPI-BR-03-C

TF-B1-SPI-BR-03-D

TF-B1-SPI-BR-04-A


TF-B1-SPI-BR-04-B

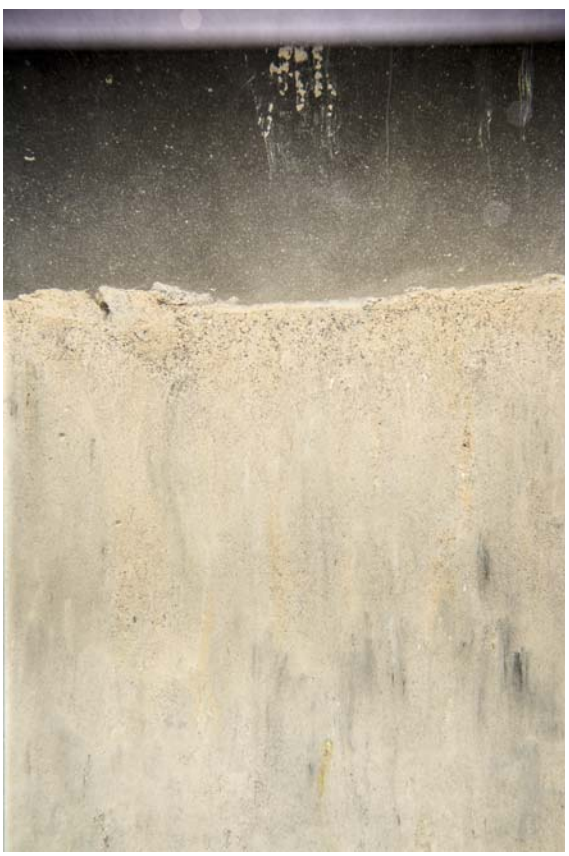

TF-B1-SPI-BR-04-C


TF-B1-SPI-BR-04-D


TF-B1-SPI-BR-05-A


TF-B1-SPI-BR-05-B


TF-B1-SPI-BR-05-C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TF-B1-SPI-BR-06-A

TF-B1-SPI-BR-06-B

TF-B1-SPI-BR-06-C

TF-B1-SPI-BR-06-D

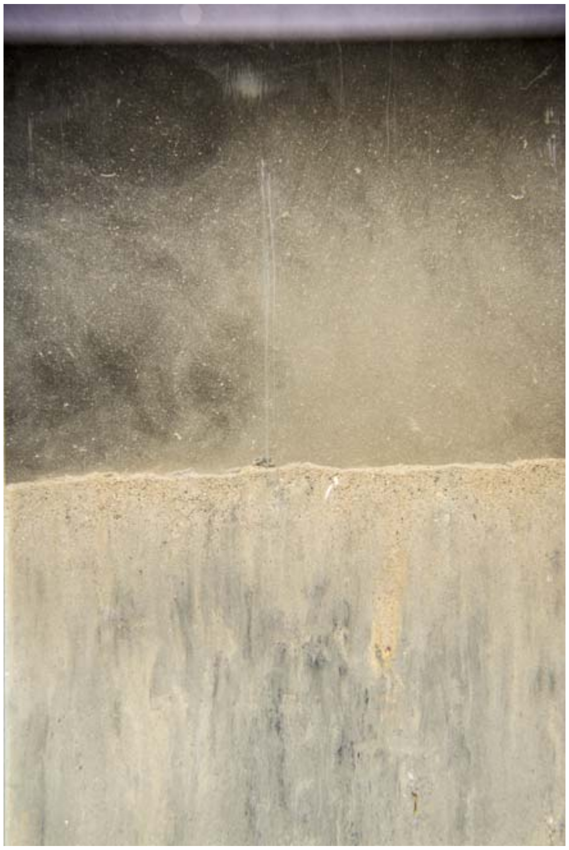
TF-B1-SPI-BR-07-A


TF-B1-SPI-BR-07-B


TF-B1-SPI-BR-07-C


TF-B1-SPI-BR-07-D


TF-B1-SPI-BR-09-A



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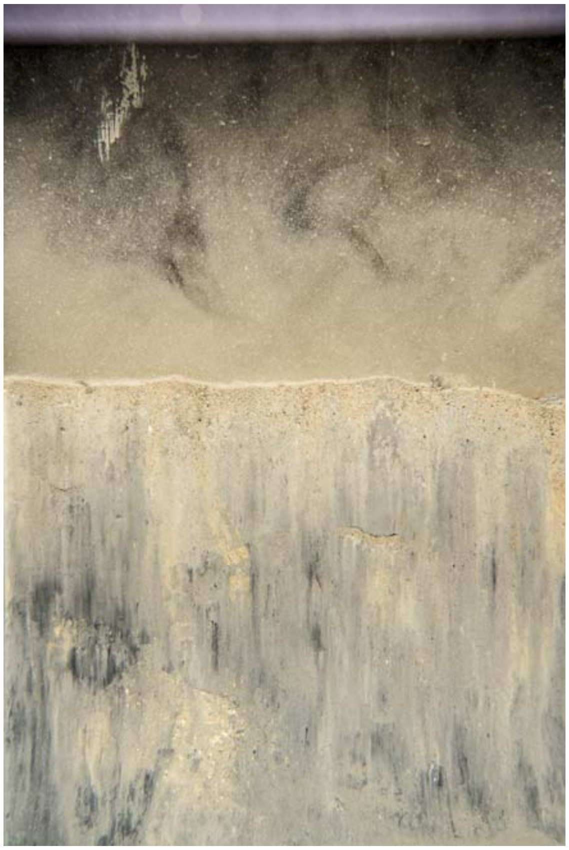
TF-B1-SPI-BR-09-C

TF-B1-SPI-BR-09-D

TF-B1-SPI-BR-10-A



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TF-B1-SPI-BR-10-C

TF-B1-SPI-BR-10-D

TF-B1-SPI-BR-11-A

TF-B1-SPI-BR-11-B

TF-B1-SPI-BR-11-C

TF-B1-SPI-BR-15-C

TF-B1-SPI-BR-15-D

TF-B1-SPI-BR-15-G

TF-B1-SPI-BR-15-H

TF-B1-SPI-BR-15-I

TF-B1-SPI-BR-16-A

TF-B1-SPI-BR-16-B

TF-B1-SPI-BR-16-C

TF-B1-SPI-BR-16-D

TF-B1-SPI-BR-18-A


TF-B1-SPI-BR-18-B


TF-B1-SPI-BR-18-C


TF-B1-SPI-BR-18-D


TF-B1-SPI-BR-21-A


TF-B1-SPI-BR-21-B


TF-B1-SPI-BR-21-C


TF-B1-SPI-BR-21-D


TF-B1-SPI-BR-22-A


TF-B1-SPI-BR-22-B


TF-B1-SPI-BR-22-C


TF-B1-SPI-BR-22-D


TF-B1-SPI-BR-23-A


TF-B1-SPI-BR-23-B


TF-B1-SPI-BR-23-C

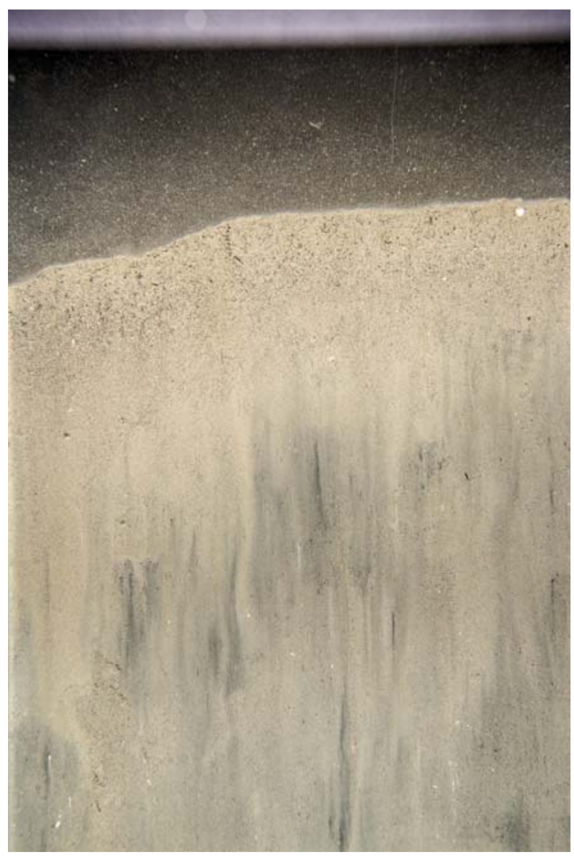

TF-B1-SPI-BR-23-D


TF-B1-SPI-BR-26-A

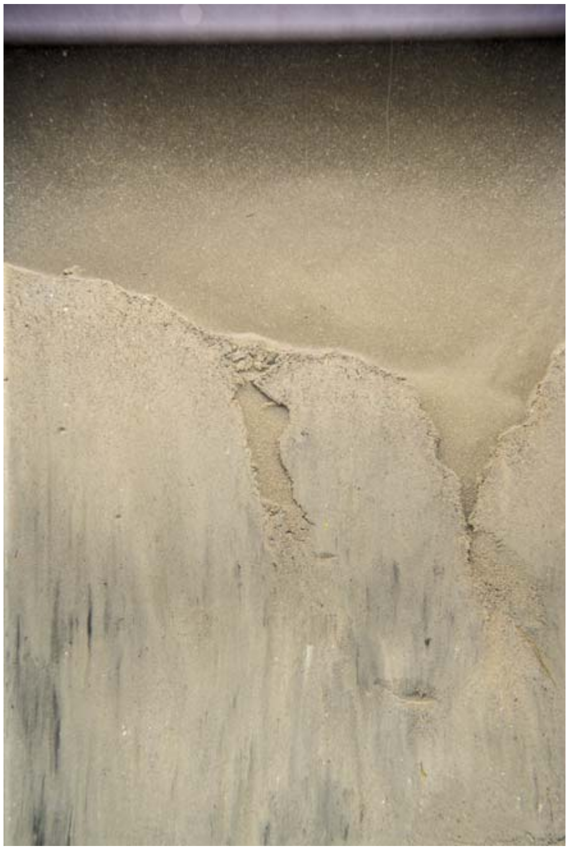
TF-B1-SPI-BR-26-B

TF-B1-SPI-BR-26-C

TF-B1-SPI-BR-26-D



TF-B1-SPI-BR-28-A



TF-B1-SPI-BR-28-B

TF-B1-SPI-BR-28-C

TF-B1-SPI-BR-28-D

TF-B1-SPI-BR-29-A

TF-B1-SPI-BR-29-B

TF-B1-SPI-BR-29-C

TF-B1-SPI-BR-29-D

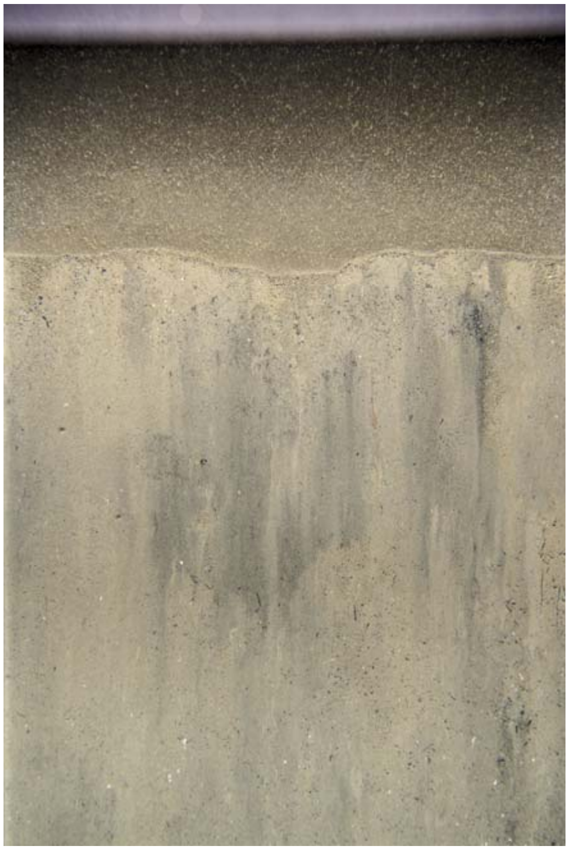
TF-B1-SPI-BR-31-A


TF-B1-SPI-BR-31-B


TF-B1-SPI-BR-31-C


TF-B1-SPI-BR-31-D


TF-B1-SPI-BR-32-A



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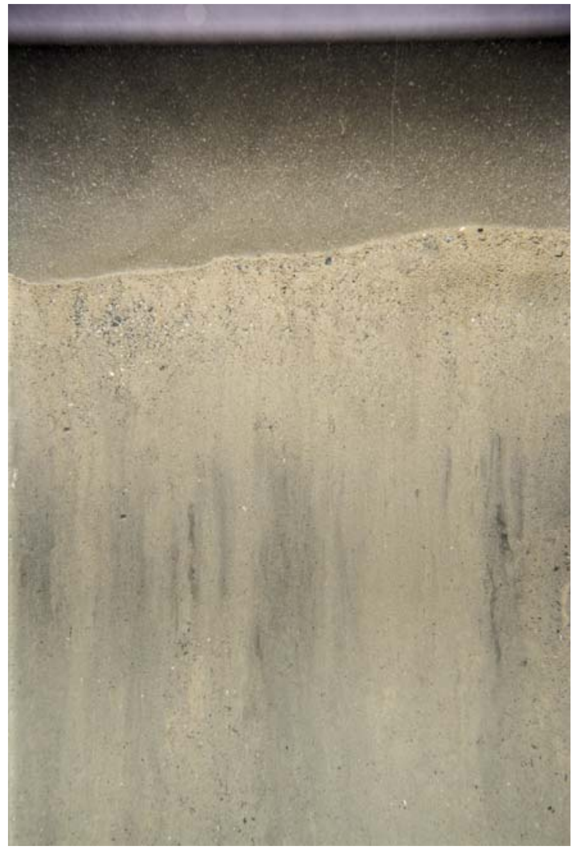
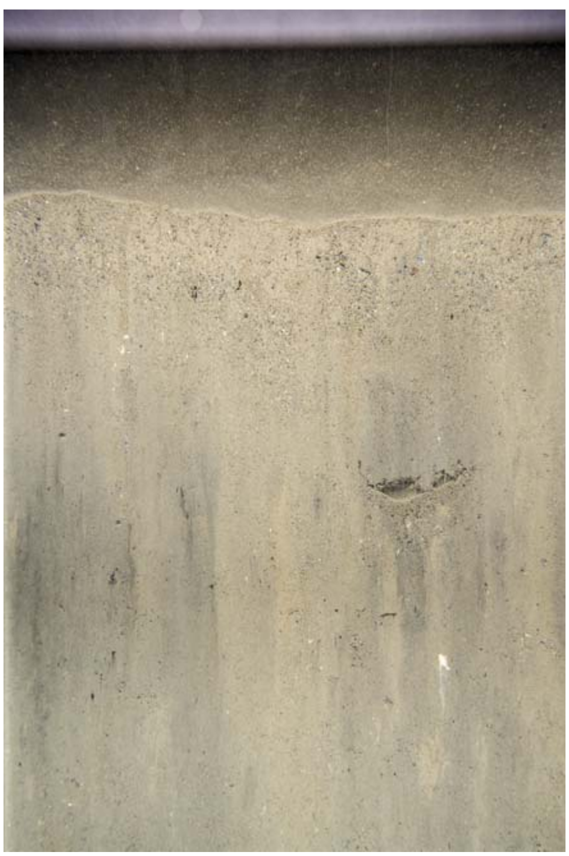


TF-B1-SPI-BR-32-C



TF-B1-SPI-BR-32-D

TF-B1-SPI-BR-33-A

TF-B1-SPI-BR-33-B

TF-B1-SPI-BR-33-C

TF-B1-SPI-BR-33-D

TF-B1-SPI-BR-33-E

TF-B1-SPI-BR-33-F

ATTACHMENT C

Benthic Infaunal Recolonization Sample Collection Forms

BENTHIC RECOLONIZATION SAMPLE COLLECTION FORM

Sample Location Designation: BR-02 Date of Collection: 7/11/14
Sample Collection Method: vanveen Weather: overcast
Field Personnel: see field book

1. Was a Surface Sediment Sample Collection Form filled out for sediment samples collected for benthic organisms (*Record location coordinates, water depth, etc. on sediment collection form) ☒ Yes ☐ No — See logbook
2. Was the SPI survey performed at sample location? ☒ Yes ☐ No
3. Was a surface sediment sample collected for archival and potential chemical analysis? ☐ Yes ☒ No

Surficial Sediment Characteristics: (circle most descriptive)

Texture:	Smooth	Fine	Coarse	Clay	Silt	some Sand	Gravel	Cobble
Color:	Light	Dark	Gray	Brown	Black	Other:		
Odor:	Normal	Petroleum	Chemical	H_2S	None	Other:		

Presence of:

	Y/N	Percent	Description Type
Biological Structures:	Y		worms, tubes, small shells, seaweed, brittle star, barnacles
Debris:	Y		woody debris, ~~se~~
Oily Sheen:	N		Rep 5 - ~10 cm oily sheen blob

Vertical Profile Characteristics:

	Description:
Changes in Sediment Characteristics:	none
Presence & Depth of Redox Potential Discontinuity Layer:	not observed in Rep 1,3 Rep 2 = ~1-2 mm Rep 4 na Rep 5

Benthic Community Samples

Approximate quantity/volume of sediment from grab screen for benthos: van veen
Size of sieve used for screening: 1mm, 0.5mm Not - 0.5 mm could not be stacked, did not have the nested, used smaller 0.5mm to sieve a portion of sample
Formalin added to sample container: yes
Sample containers filled (number and type): 5-1L
Comments/Notes: GPS coordinates in logbook
labeled BR-02-Y10-R1 to R5 0-10 cm
9:20 Rep1 39.0 ft 10:00 Rep 4 40.7'
9:45 Rep2 39.7 ft 10:05 Rep 5 38.4'
9:50 Rep3 40.25'

BENTHIC RECOLONIZATION SAMPLE COLLECTION FORM

Sample Location Designation: BR-03 Date of Collection: 7/11/14
Sample Collection Method: van veen Weather: overcast ~65°
Field Personnel: see field book

1. Was a Surface Sediment Sample Collection Form filled out for sediment samples collected for benthic organisms (*Record location coordinates, water depth, etc. on sediment collection form) see logbook ☒ Yes ☐ No
2. Was the SPI survey performed at sample location? ☐ ~~Yes~~ ☐ No
3. Was a surface sediment sample collected for archival and potential chemical analysis? ☐ Yes ☒ No

Surficial Sediment Characteristics: (circle most descriptive) trace/slight

Texture:	Smooth	Fine	Coarse	Clay	Silt	Sand	Gravel	Cobble
Color:	Light	Dark	Gray	Brown	Black	Other:		
Odor:	Normal	Petroleum	Chemical	H_2S	None	Other:		

Presence of:

	Y/N	Percent	Description Type
Biological Structures:	Y		worms, casings, small ~0.5 cm crab,
Debris:	Y		woody debris, small lead weight small shells ~1cm ~3cm, broken shells 2-3cm clam
Oily Sheen:	N		

Vertical Profile Characteristics:

	Description:
Changes in Sediment Characteristics:	none
Presence & Depth of Redox Potential Discontinuity Layer:	~1cm RPD

Benthic Community Samples

Approximate quantity/volume of sediment from grab screen for benthos: ~1/2 van veen
Size of sieve used for screening: 0.5mm, 1.0 mm
Formalin added to sample container: yes
Sample containers filled (number and type): 5-1 Liter
Comments/Notes GPS coordinates in logbook
labeled BR-03-410-R1 to R5 0-10 cm
Rep 1 10:45 Rep 4 11:30
Rep 2 11:00 Rep 5 11:40
Rep 3 11:20

BENTHIC RECOLONIZATION SAMPLE COLLECTION FORM

Sample Location Designation: BR-04 Date of Collection: 7/11/16
Sample Collection Method: van veen Weather: partly sunny ~70°
Field Personnel: see logbook

1. Was a Surface Sediment Sample Collection Form filled out for sediment samples collected for benthic organisms (*Record location coordinates, water depth, etc. on sediment collection form) see logbook ☒ Yes ☐ No
2. Was the SPI survey performed at sample location? ☒ Yes ☐ No
3. Was a surface sediment sample collected for archival and potential chemical analysis? ☐ Yes ☒ No

Surficial Sediment Characteristics: (circle most descriptive) slight/some fine

Texture:	Smooth	Fine	Coarse	Clay	Silt	Sand	Gravel	Cobble
Color:	Light	Dark	Gray	Brown	Black	Other:		
Odor:	Normal	Petroleum	Chemical	H_2S	None	Other:		

Presence of:

	Y/N	Percent	Description Type
Biological Structures:	Y		worms, kelp, brittlestar, casings, small shells
Debris:	Y		woody debris
Oily Sheen:	N		

Vertical Profile Characteristics:

	Description:
Changes in Sediment Characteristics:	none
Presence & Depth of Redox Potential Discontinuity Layer:	~0.5-1 cm

Benthic Community Samples

Approximate quantity/volume of sediment from grab screen for benthos: ~1/2 van veen
Size of sieve used for screening: 0.5 mm, 1mm
Formalin added to sample container: yes
Sample containers filled (number and type): 5 - 1 Liter
Comments/Notes GPS coordinates in logbook
labeled BR-04-410-R1 to R5 0-10 cm
Rep 1 1155 Rep 4 1235
Rep 2 1205 Rep 5 1240
Rep 3 1230

BENTHIC RECOLONIZATION SAMPLE COLLECTION FORM

Sample Location Designation: BR-05 Date of Collection: 7/11/16
Sample Collection Method: van veen Weather: partly sunny, ~65°
Field Personnel: see logbook

1. Was a Surface Sediment Sample Collection Form filled out for sediment samples collected for benthic organisms (*Record location coordinates, water depth, etc. on sediment collection form) see logbook ☒ Yes ☐ No
2. Was the SPI survey performed at sample location? ☒ Yes ☐ No
3. Was a surface sediment sample collected for archival and potential chemical analysis? ☐ Yes ☒ No

Surficial Sediment Characteristics: (circle most descriptive) slight fine to med

Texture:	Smooth	Fine	Coarse	Clay	Silt	Sand	Gravel	Cobble
Color:	~~Light~~	Dark	Gray	Brown	~~Black~~	~~Other~~:		
Odor:	Normal	~~Petroleum~~	Chemical	H_2S	None	Other:		

Presence of:

	Y/N	Percent	Description Type
Biological Structures:	Y		worms, casings, small shells, brittle star, clam ~
Debris:	Y		small wood pieces, garbage 5 cm
Oily Sheen:	N		

Vertical Profile Characteristics:

	Description:
Changes in Sediment Characteristics:	none
Presence & Depth of Redox Potential Discontinuity Layer:	½-1.0 cm

Benthic Community Samples

Approximate quantity/volume of sediment from grab screen for benthos: 3/4 van veen
Size of sieve used for screening: 0.5 mm, 1 mm
Formalin added to sample container: yes
Sample containers filled (number and type): 5 - 1 liter
Comments/Notes GPS coordinates in logbook
labeled BR-05-410-R1 to R5 0-10 cm
Rep 1 14:11
Rep 2 14:32 Rep 4 1450
Rep 3 14:40 Rep 5 1500

BENTHIC RECOLONIZATION SAMPLE COLLECTION FORM

Sample Location Designation: BR-06 Date of Collection: 7/11/16
Sample Collection Method: van veen Weather: partly sunny ~70°
Field Personnel: see logbook

1. Was a Surface Sediment Sample Collection Form filled out for sediment samples collected for benthic organisms (*Record location coordinates, water depth, etc. on sediment collection form) see logbook ☒ Yes ☐ No
2. Was the SPI survey performed at sample location? ☒ Yes ☐ No
3. Was a surface sediment sample collected for archival and potential chemical analysis? ☐ Yes ☒ No

Surficial Sediment Characteristics: (circle most descriptive)

Texture:	Smooth	Fine	Coarse	Clay	Silt	Sand trace	Gravel	Cobble
Color:	Light	Dark	Gray	Brown	Black	Other:		
Odor:	Normal	Petroleum	Chemical	H_2S	None	Other:		

Presence of:

	Y/N	Percent	Description Type
Biological Structures:	Y		worms casings, small shells, kelp
Debris:	Y		small leaves, woody debris, piece of garbage, ~3 cm clam
Oily Sheen:	N		

Vertical Profile Characteristics:

	Description:
Changes in Sediment Characteristics:	none
Presence & Depth of Redox Potential Discontinuity Layer:	~ 1-2 cm

Benthic Community Samples

Approximate quantity/volume of sediment from grab screen for benthos: ~1/2 to 3/4 vanveen
Size of sieve used for screening: 0.5 mm, 1 mm
Formalin added to sample container: yes
Sample containers filled (number and type): 5 - 1 Liter
Comments/Notes: GPS coordinates in logbook
labeled BR-06-410-R1 to R5 0-10 cm
Rep 1 1515 Rep 4 1620
Rep 2 1530 Rep 5 1630
Rep 3 1610

BENTHIC RECOLONIZATION SAMPLE COLLECTION FORM

Sample Location Designation: BR-07 Date of Collection: 7/12/13

Sample Collection Method: van veen Weather: overcast ~55

Field Personnel: see logbook

1. Was a Surface Sediment Sample Collection Form filled out for sediment samples collected for benthic organisms (*Record location coordinates, water depth, etc. on sediment collection form) see logbook ☒ Yes ☐ No
2. Was the SPI survey performed at sample location? ☒ Yes ☐ No
3. Was a surface sediment sample collected for archival and potential chemical analysis? ☐ Yes ☒ No

Surficial Sediment Characteristics: (circle most descriptive) trace/slight

Texture:	Smooth	Fine	Coarse	Clay	Silt	Sand	Gravel	Cobble
Color:	Light	Dark	Gray	Brown	Black	Other:		
Odor:	Normal	Petroleum	Chemical	H_2S	None	Other:		

Presence of:

	Y/N	Percent	Description Type
Biological Structures:	Y		worms, casings, small brittle star, small shells, a few 2-3 cm clamshells
Debris:	Y		small pieces of trash, a few leaves
Oily Sheen:	N		

Vertical Profile Characteristics:

	Description:
Changes in Sediment Characteristics:	none
Presence & Depth of Redox Potential Discontinuity Layer:	~ 0.5 - 2 cm

Benthic Community Samples

Approximate quantity/volume of sediment from grab screen for benthos: ~ 1/2 van veen

Size of sieve used for screening: 0.5 mm, 1mm

Formalin added to sample container: yes

Sample containers filled (number and type): 5 - 500 ml

Comments/Notes GPS coordinates in logbook

labeled BR-07-Y10-R1 to R5 0-10 cm

Rep 1 9:00 Rep 4 920

Rep 2 905 Rep 5 925

Rep 3 915

Thea Foss and Wheeler-Osgood Waterways OMMP

BENTHIC RECOLONIZATION SAMPLE COLLECTION FORM

Sample Location Designation: BR-09 Date of Collection: 7/12/15

Sample Collection Method: Van veen Weather: partly sunny ~60

Field Personnel: See logbook

1. Was a Surface Sediment Sample Collection Form filled out for sediment samples collected for benthic organisms (*Record location coordinates, water depth, etc. on sediment collection form) See logbook ☒ Yes ☐ No
2. Was the SPI survey performed at sample location? ☒ Yes ☐ No
3. Was a surface sediment sample collected for archival and potential chemical analysis? ☐ Yes ☒ No

Surficial Sediment Characteristics: (circle most descriptive)

Texture:	Smooth	Fine	Coarse	Clay	Silt	Sand fine to coarse sand	Gravel fine to med	Cobble small cobble
Color:	Light	Dark	Gray	Brown	Black	Other:		
Odor:	Normal	Petroleum	Chemical	H_2S	None	Other:		

Presence of:

	Y/N	Percent	Description Type
Biological Structures:	y		175cm worms, small brittle stars, 2-3 cm clam shells, small shells, casings barnacle's
Debris:	y		small pieces of garbage
Oily Sheen:	N		

Vertical Profile Characteristics:

	Description:
Changes in Sediment Characteristics:	none
Presence & Depth of Redox Potential Discontinuity Layer:	~3-4cm

Benthic Community Samples

Approximate quantity/volume of sediment from grab screen for benthos: ~1/2 van veen

Size of sieve used for screening: 0.5mm, 1mm

Formalin added to sample container: yes

Sample containers filled (number and type): 5 - 1 Liter

Comments/Notes GPS coordinates in logbook

labeled BR-09-41-01 to R5 0-10cm

Rep 1 945 Rep 4 1020

Rep 2 950 Rep 5 1025

Rep 3 1005

BENTHIC RECOLONIZATION SAMPLE COLLECTION FORM

Sample Location Designation: BR-10 Date of Collection: 7/12/16

Sample Collection Method: Van veen Weather: Sunny ~65°

Field Personnel: see logbook

1. Was a Surface Sediment Sample Collection Form filled out for sediment samples collected for benthic organisms (*Record location coordinates, water depth, etc. on sediment collection form) see logbook ☒ Yes ☐ No
2. Was the SPI survey performed at sample location? ☒ Yes ☐ No
3. Was a surface sediment sample collected for archival and potential chemical analysis? ☐ Yes ☒ No

Surficial Sediment Characteristics: (circle most descriptive) fine to medium

Texture:	Smooth	Fine	Coarse	Clay	Silt	Sand	Gravel	Cobble
Color:	Light	Dark	Gray	Brown	Black	Other:		
Odor:	Normal	Petroleum	Chemical	H_2S	None	Other:		

Presence of:

	Y/N	Percent	Description Type
Biological Structures:	Y		worms, casings, small shells, ~3 cm clam shell, hermit crab, ~1 cm crab
Debris:	Y		woody debris, rope
Oily Sheen:	N		

Vertical Profile Characteristics:

	Description:
Changes in Sediment Characteristics:	none
Presence & Depth of Redox Potential Discontinuity Layer:	~ 0.5 - 2cm

Benthic Community Samples

Approximate quantity/volume of sediment from grab screen for benthos: ~1/2 van veen

Size of sieve used for screening: 0.5mm, 1mm

Formalin added to sample container: yes

Sample containers filled (number and type): 5 - 1 liter

Comments/Notes: GPS coordinates in logbook

labeled BR-10-410-R1 to R5 0-10 cm

Rep 1 1035 Rep 4 1100

Rep 2 1045 Rep 5 1110

Rep 3 1055

BENTHIC RECOLONIZATION SAMPLE COLLECTION FORM

Sample Location Designation: BR-11 Date of Collection: 7/12/16

Sample Collection Method: van veen Weather: Sunny ~65°

Field Personnel: see logbook

1. Was a Surface Sediment Sample Collection Form filled out for sediment samples collected for benthic organisms (*Record location coordinates, water depth, etc. on sediment collection form) see logbook ☐ Yes ☐ No
2. Was the SPI survey performed at sample location? ☒ Yes ☐ No
3. Was a surface sediment sample collected for archival and potential chemical analysis? ☐ Yes ☒ No

Surficial Sediment Characteristics: (circle most descriptive) slight fine

Texture:	Smooth	Fine	Coarse	Clay	Silt	Sand	Gravel	Cobble
Color:	Light	Dark	Gray	Brown	Black	Other:		
Odor:	Normal	Petroleum	Chemical	H_2S	None	Other:		

Presence of:

	Y/N	Percent	Description Type
Biological Structures:	Y		worms, casings, small shells
Debris:	Y		leafy debris, piece of plastic
Oily Sheen:	N		

Vertical Profile Characteristics:

	Description:
Changes in Sediment Characteristics:	
Presence & Depth of Redox Potential Discontinuity Layer:	~2-3 mm

Benthic Community Samples

Approximate quantity/volume of sediment from grab screen for benthos: ~1/2 van veen

Size of sieve used for screening: 0.5 mm, 1mm

Formalin added to sample container: yes

Sample containers filled (number and type): 5 - 500 ml

Comments/Notes GPS coordinates in log book

Labeled BR-11-Y10 - R1 to R5

Rep 1 1130 Rep 4 1200

Rep 2 1140 Rep 5 1205

Rep 3 1150

BENTHIC RECOLONIZATION SAMPLE COLLECTION FORM

Sample Location Designation: BR-15 Date of Collection: 9/12/16
Sample Collection Method: van veen Weather: sunny ~70°
Field Personnel: see logbook

1. Was a Surface Sediment Sample Collection Form filled out for sediment samples collected for benthic organisms (*Record location coordinates, water depth, etc. on sediment collection form) see logbook ☒ Yes ☐ No
2. Was the SPI survey performed at sample location? ☒ Yes ☐ No
3. Was a surface sediment sample collected for archival and potential chemical analysis? ☒ Yes ☐ No

Surficial Sediment Characteristics: (circle most descriptive) slight/some fine sand

Texture: Smooth Fine Coarse | Clay Silt Sand Gravel Cobble
Color: Light Dark | Gray Brown Black Other:
Odor: Normal Petroleum Chemical H_2S None Other:

Presence of:

	Y/N	Percent	Description Type
Biological Structures:	Y		worms, casings, small shells
Debris:	Y		small pieces of garbage
Oily Sheen:	N		

Vertical Profile Characteristics:

	Description:
Changes in Sediment Characteristics:	none
Presence & Depth of Redox Potential Discontinuity Layer:	~1-2 cm

Benthic Community Samples

Approximate quantity/volume of sediment from grab screen for benthos: 1/2 van veen
Size of sieve used for screening: 0.5mm, 1mm
Formalin added to sample container: yes
Sample containers filled (number and type): Rep 1,4,5,6 - 1 Liters Rep-2,3 - 500 ml each
Comments/Notes GPS Coordinates in logbook
labeled BR-15-Y10-R1 to R6 0-10 cm
BR-15-Y10-R1 - Chemistry
Rep 1 1350 Rep 3 1410 Rep 5 1450
Rep 2 1400 Rep 4 1430 Rep 6 1500

BENTHIC RECOLONIZATION SAMPLE COLLECTION FORM

Sample Location Designation: BR-16 Date of Collection: 7/12/16

Sample Collection Method: vanveen Weather: sunny -70°

Field Personnel: see logbook

1. Was a Surface Sediment Sample Collection Form filled out for sediment samples collected for benthic organisms (*Record location coordinates, water depth, etc. on sediment collection form) see logbook ☒ Yes ☐ No
2. Was the SPI survey performed at sample location? ☒ Yes ☐ No
3. Was a surface sediment sample collected for archival and potential chemical analysis? ☐ Yes ☒ No

Surficial Sediment Characteristics: (circle most descriptive) some fine to coarse

Texture:	Smooth	Fine	Coarse	Clay	Silt	Sand	Gravel	Cobble
Color:	Light	Dark	Gray	Brown	Black	Other:		
Odor:	Normal	Petroleum	Chemical	H_2S	None	Other:		

Presence of:

	Y/N	Percent	Description Type
Biological Structures:	Y		worms, casings, ~3cm clam shells, small shells
Debris:	~~N~~ Y		leafy debris - a few leaves
Oily Sheen:	N		

Vertical Profile Characteristics:

	Description:
Changes in Sediment Characteristics:	none
Presence & Depth of Redox Potential Discontinuity Layer:	~2-3cm RPD

Benthic Community Samples

Approximate quantity/volume of sediment from grab screen for benthos: ~ 1/3 - 1/2 van veen

Size of sieve used for screening: 0.5mm, 1mm

Formalin added to sample container: yes

Sample containers filled (number and type): 5 - 1 liter

Comments/Notes See logbook for GPS coordinates

labeled BR-16-Y10-R1 to R5

Rep 1 1530 10cm Rep 4 1545 9.5 cm

Rep 2 1535 8.5cm Rep 5 1550 9.0 cm

Rep 3 1540 9 cm

BENTHIC RECOLONIZATION SAMPLE COLLECTION FORM

Sample Location Designation: BR-18 Date of Collection: 7/12/16

Sample Collection Method: van veen Weather: sunny ~70°F

Field Personnel: see logbook

1. Was a Surface Sediment Sample Collection Form filled out for sediment samples collected for benthic organisms (*Record location coordinates, water depth, etc. on sediment collection form) see logbook ☐ Yes ☐ No
2. Was the SPI survey performed at sample location? ☒ Yes ☐ No
3. Was a surface sediment sample collected for archival and potential chemical analysis? ☐ Yes ☒ No

Surficial Sediment Characteristics: (circle most descriptive)

Texture:	Smooth	~~Fine~~	Coarse	Clay	~~Silt~~	Sand	Gravel	Cobble
Color:	Light	Dark	Gray	Brown	Black	Other:		
Odor:	Normal	Petroleum	Chemical	H_2S	None	Other:	silt w/ sand and gravel	

Presence of:

	Y/N	Percent	Description Type
Biological Structures:	Y		worms casings, small shells, 3-4 cm clams
Debris:	N		~10-15 cm live crabs, large clamshells
Oily Sheen:	N		mussel shells

Vertical Profile Characteristics:

	Description:
Changes in Sediment Characteristics:	none
Presence & Depth of Redox Potential Discontinuity Layer:	~ 0.5-1 cm

Benthic Community Samples

Approximate quantity/volume of sediment from grab screen for benthos: ~1/2 van veen

Size of sieve used for screening: 0.5mm, 1mm

Formalin added to sample container: yes

Sample containers filled (number and type): 5 - 1 liter

Comments/Notes: GPS coordinates in logbook

labeled BR-18-Y10-R1 to R5

Rep1 1600 Rep3 1615 Rep5 1630

Rep2 1610 Rep4 1620

BENTHIC RECOLONIZATION SAMPLE COLLECTION FORM

Sample Location Designation: BR-21c Date of Collection: 7/13/16
Sample Collection Method: van veen Weather: partly cloudy, ~65°
Field Personnel: see logbook

1. Was a Surface Sediment Sample Collection Form filled out for sediment samples collected for benthic organisms (*Record location coordinates, water depth, etc. on sediment collection form) ☒ Yes ☐ No
2. Was the SPI survey performed at sample location? ☒ Yes ☐ No
3. Was a surface sediment sample collected for archival and potential chemical analysis? ☒ Yes ☐ No

Surficial Sediment Characteristics: (circle most descriptive) slight fine

Texture: Smooth | Fine | Coarse | Clay | Silt | Sand | Gravel | Cobble
Color: Light | Dark | Gray | Brown | Black | Other:
Odor: Normal | Petroleum | Chemical | H_2S | None | Other:

Presence of:

	Y/N	Percent	Description Type
Biological Structures:	Y	very little	worms, casing, small shells
Debris:	Y		newspaper
Oily Sheen:	N		

Vertical Profile Characteristics:

	Description:
Changes in Sediment Characteristics:	none
Presence & Depth of Redox Potential Discontinuity Layer:	~2-3 mm RPD, Rep 3 ~0.5 cm

Benthic Community Samples

Approximate quantity/volume of sediment from grab screen for benthos: ~1/2 van veen
Size of sieve used for screening: 0.5 mm, 1.0 mm
Formalin added to sample container: yes
Sample containers filled (number and type): 5 - 500 ml
Comments/Notes GPS coordinates in logbook
labeled BR-21-410-R1 to R6 (R1 = chemistry sample)
Rep 1 910 Rep 4 1005
Rep 2 925 Rep 5 1015
Rep 3 955 Rep 6 1025

BENTHIC RECOLONIZATION SAMPLE COLLECTION FORM

Sample Location Designation: BR-22 Date of Collection: 7/13/16
Sample Collection Method: Van Veen Weather: cloudy 265°
Field Personnel: see logbook

1. Was a Surface Sediment Sample Collection Form filled out for sediment samples collected for benthic organisms (*Record location coordinates, water depth, etc. on sediment collection form) see logbook ☒ Yes ☐ No
2. Was the SPI survey performed at sample location? ☒ Yes ☐ No
3. Was a surface sediment sample collected for archival and potential chemical analysis? ☒ Yes ☐ No

Surficial Sediment Characteristics: (circle most descriptive) slight / some fine

Texture:	Smooth	Fine	Coarse	Clay	Silt	Sand	Gravel	Cobble
Color:	Light	Dark	Gray	Brown	Black	Other:		
Odor:	Normal	Petroleum	Chemical	H_2S	None	Other:		

Presence of:

	Y/N	Percent	Description Type
Biological Structures:	Y		worms, casings, small shells, several small shrimp(?)
Debris:	Y		leafy debris
Oily Sheen:	N		

Vertical Profile Characteristics:

	Description:
Changes in Sediment Characteristics:	none
Presence & Depth of Redox Potential Discontinuity Layer:	~ 1-2 cm

Benthic Community Samples

Approximate quantity/volume of sediment from grab screen for benthos: ~1/2-3/4 Van Veen
Size of sieve used for screening: 0.5 mm, 1.0 mm
Formalin added to sample container: yes
Sample containers filled (number and type):
Comments/Notes GPS coordinates in logbook
labeled BR-22-410-R1 to R6 Rb-chemistry
Rep 6 1040 Rep 3 1100
Rep 1 1045 Rep 4 1115
Rep 2 1050 Rep 5 1120

BENTHIC RECOLONIZATION SAMPLE COLLECTION FORM

Sample Location Designation: BR-23 Date of Collection: 7/13/16
Sample Collection Method: Van veen Weather: partly sunny ~65°
Field Personnel: See logbook

1. Was a Surface Sediment Sample Collection Form filled out for sediment samples collected for benthic organisms (*Record location coordinates, water depth, etc. on sediment collection form) See logbook ☐ Yes ☐ No
2. Was the SPI survey performed at sample location? ☒ Yes ☐ No
3. Was a surface sediment sample collected for archival and potential chemical analysis? ☐ Yes ☒ No

Surficial Sediment Characteristics: (circle most descriptive) slight fine toned

Texture:	Smooth	Fine	Coarse	Clay	Silt	Sand	Gravel	Cobble few small
Color:	Light	Dark	Gray	Brown	Black	Other:		
Odor:	Normal	Petroleum	Chemical	H_2S strong	None	Other: organic smell, strong		

Presence of:

	Y/N	Percent	Description Type
Biological Structures:	Y		few shrimp, ~10 cm sculpin, small eel, broken clam shell
Debris:	Y		plastic pieces, mostly leafy debris, woody debris
Oily Sheen:	N		

Vertical Profile Characteristics:

	Description:
Changes in Sediment Characteristics:	appears to be very thin RPD, wasn't previous sampling
Presence & Depth of Redox Potential Discontinuity Layer:	~3-5 MM

Benthic Community Samples

Approximate quantity/volume of sediment from grab screen for benthos: ~3/4 van veen
Size of sieve used for screening: 0.5 mm, 1mm
Formalin added to sample container: yes
Sample containers filled (number and type): 5 - 1 liter
Comments/Notes GPS coordinates in logbook
labeled BR-23-410-R1 to R5 0-10 cm
Rep 1 1310 Rep 4 1335
Rep 2 1315 Rep 5 1340
Rep 3 1325

BENTHIC RECOLONIZATION SAMPLE COLLECTION FORM

Sample Location Designation: BR-26 Date of Collection: 7/13/16
Sample Collection Method: van veen Weather: partly cloudy ~65°
Field Personnel: see logbook

1. Was a Surface Sediment Sample Collection Form filled out for sediment samples collected for benthic organisms (*Record location coordinates, water depth, etc. on sediment collection form) see logbook ☐ Yes ☐ No
2. Was the SPI survey performed at sample location? ☒ Yes ☐ No
3. Was a surface sediment sample collected for archival and potential chemical analysis? ☐ Yes ☒ No

Surficial Sediment Characteristics: (circle most descriptive) fine to coarse sand, small gravel

Texture:	Smooth	Fine	Coarse	Clay	Silt	Sand	Gravel	Cobble
Color:	Light	Dark	Gray	Brown	Black	Other:	cap material -	
Odor:	Normal	Petroleum	Chemical	H_2S	None	Other:	Mostly	

Presence of:

	Y/N	Percent	Description Type
Biological Structures:	Y		small clam shells, worms, casings, several shrimp,
Debris:	N		~4 cm sea slug, small hermit crab
Oily Sheen:	N		2 crab ~10 cm

Vertical Profile Characteristics:

	Description:
Changes in Sediment Characteristics:	yes, thin silt layer ontop → 0.5 to 1 cm
Presence & Depth of Redox Potential Discontinuity Layer:	

Benthic Community Samples

Approximate quantity/volume of sediment from grab screen for benthos: ~1/2 van veen
Size of sieve used for screening: 0.5 mm, 1.0 mm
Formalin added to sample container: yes
Sample containers filled (number and type): 5 - 1 Lite
Comments/Notes GPS coordinates in logbook
labelled BR-26-410-R1 to R5
Rep 1 1400 Rep 4 1415
Rep 2 1405 Rep 5 1425
Rep 3 1410

BENTHIC RECOLONIZATION SAMPLE COLLECTION FORM

Sample Location Designation: BR-28 Date of Collection: 7/13/16
Sample Collection Method: van veen Weather: partly cloudy ~65°
Field Personnel: see logbook

1. Was a Surface Sediment Sample Collection Form filled out for sediment samples collected for benthic organisms (*Record location coordinates, water depth, etc. on sediment collection form) ☒ Yes ☐ No
2. Was the SPI survey performed at sample location? ☒ Yes ☐ No
3. Was a surface sediment sample collected for archival and potential chemical analysis? ☒ Yes ☐ No

Surficial Sediment Characteristics: (circle most descriptive)

trace fine

Texture:	Smooth	Fine	Coarse	Clay	Silt	Sand	Gravel	Cobble
Color:	Light	Med Dark	Gray	Brown	Black	Other:		
Odor:	Normal	Petroleum	Chemical	H_2S	None	Other:		

Presence of:

	Y/N	Percent	Description Type
Biological Structures:	Y		worms, few shrimp, broken clam shells, some large
Debris:	Y		woody/plast debris mussel shells, shrimp casing; ~3 to 4 cm
Oily Sheen:	N		

Vertical Profile Characteristics:

	Description:
Changes in Sediment Characteristics:	
Presence & Depth of Redox Potential Discontinuity Layer:	~ 2-3 mm lighter silt on top, maybe RPD or depositional layer

Benthic Community Samples

Approximate quantity/volume of sediment from grab screen for benthos: 3/4 van veen
Size of sieve used for screening: 0.5 mm, 1mm
Formalin added to sample container: yes
Sample containers filled (number and type): 7- 500 ml
Comments/Notes GPS coordinates in logbook
labeled BR-28-Y10-R1 to R6 (R1 = chemistry)
Rep 1 1435 Rep 3 1500 Rep 6 1525
Rep Dup 1440 Rep 4 1510
Rep 2 1450 Rep 5 1515

BENTHIC RECOLONIZATION SAMPLE COLLECTION FORM

Sample Location Designation: BR-29 Date of Collection: 7/13/16
Sample Collection Method: van veen Weather: partly cloudy ~70
Field Personnel: see logbook

1. Was a Surface Sediment Sample Collection Form filled out for sediment samples collected for benthic organisms (*Record location coordinates, water depth, etc. on sediment collection form) see logbook ☐ Yes ☐ No
2. Was the SPI survey performed at sample location? ☒ Yes ☐ No
3. Was a surface sediment sample collected for archival and potential chemical analysis? ☐ Yes ☒ No

Surficial Sediment Characteristics: (circle most descriptive) ~~most~~ – some small gravel

Texture:	Smooth	Fine	med to Coarse	Clay	Silt	Sand	Gravel	Cobble
Color:	Light	Dark	Gray	Brown	Black	Other:		
Odor:	Normal	Petroleum	Chemical	H_2S	None	Other:		

Presence of:

	Y/N	Percent	Description Type
Biological Structures:	Y		worms casings, clam shells, shrimp, ~1cm crab,
Debris:	N		mussel shells
Oily Sheen:	N		

Vertical Profile Characteristics:

	Description:
Changes in Sediment Characteristics:	
Presence & Depth of Redox Potential Discontinuity Layer:	~1-2 cm med brown silt deposition

Benthic Community Samples

Approximate quantity/volume of sediment from grab screen for benthos: ~1/2 van veen
Size of sieve used for screening: 0.5mm, 1mm
Formalin added to sample container: yes
Sample containers filled (number and type):
Comments/Notes GPS coordinates in logbook
labeled BR-29-Y1-R1 to R5
Rep 1 1540 Rep 4 1600
Rep 2 1545 Rep 5 1605
Rep 3 1550

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BENTHIC RECOLONIZATION SAMPLE COLLECTION FORM

Sample Location Designation: BR-31 Date of Collection: 7/14/16

Sample Collection Method: vanveen Weather: Sunny ~60°

Field Personnel: See logbook

1. Was a Surface Sediment Sample Collection Form filled out for sediment samples collected for benthic organisms (*Record location coordinates, water depth, etc. on sediment collection form) see logbook ☐ Yes ☐ No
2. Was the SPI survey performed at sample location? ☒ Yes ☐ No
3. Was a surface sediment sample collected for archival and potential chemical analysis? ☐ Yes ☒ No

Surficial Sediment Characteristics: (circle most descriptive)

Texture:	Smooth	Fine	Coarse	Clay	Silt	Sand sand (fine to coarse)	Gravel small	Cobble
Color:	Light	Dark	Gray	Brown	Black	Other: cap material		
Odor:	Normal	Petroleum	Chemical	H_2S	None	Other:		

Presence of:

	Y/N	Percent	Description Type
Biological Structures:	y		Mussel shells, clam shells, large snail ~6-8 cm, baby geoduck, worms, shrimp
Debris:	Y		minor leafy and woody debris
Oily Sheen:	N		

Vertical Profile Characteristics:

	Description:
Changes in Sediment Characteristics:	none
Presence & Depth of Redox Potential Discontinuity Layer:	~0.5-1cm depositional med brown silt

Benthic Community Samples

Approximate quantity/volume of sediment from grab screen for benthos: ~1/2 van veen

Size of sieve used for screening: 0.5mm, 1mm

Formalin added to sample container: yes

Sample containers filled (number and type): 5 - 1 Liter

Comments/Notes: GPS coordinates in logbook

labeled BR-31-410-R1 to R5 0-10 cm

Rep 1 915 Rep 4 935

Rep 2 925 Rep 5 940

Rep 3 930

BENTHIC RECOLONIZATION SAMPLE COLLECTION FORM

Sample Location Designation: BR-32 Date of Collection: 7/14/16

Sample Collection Method: vanveen Weather: sunny ~65°

Field Personnel: see logbook

1. Was a Surface Sediment Sample Collection Form filled out for sediment samples collected for benthic organisms (*Record location coordinates, water depth, etc. on sediment collection form) see logbook ☐ Yes ☐ No
2. Was the SPI survey performed at sample location? ☒ Yes ☐ No
3. Was a surface sediment sample collected for archival and potential chemical analysis? ☐ Yes ☒ No

Surficial Sediment Characteristics: (circle most descriptive)

fine to med

Texture:	Smooth	Fine	Coarse	Clay	Silt	Sand	Gravel	Cobble
Color:	Light	Dark	Gray	Brown	Black	Other: cap material		
Odor:	Normal	Petroleum	Chemical	H_2S	None	Other:		

Presence of:

	Y/N	Percent	Description Type
Biological Structures:	Y		large shrimp ~25cm (threw back), smaller shrimp,
Debris:	Y		plastic bag, 3-4 cm clams, clam shells
Oily Sheen:	N		leafy debris, barnacles

like crab 5-7 cm large clam shell ~3 cm

Vertical Profile Characteristics:

	Description:
Changes in Sediment Characteristics:	~~[illegible]~~ more silt than previous sampling
Presence & Depth of Redox Potential Discontinuity Layer:	~~[illegible]~~ 5-8 cm depositional layer AM

Benthic Community Samples

Approximate quantity/volume of sediment from grab screen for benthos: ~1/2 - 3/4 van veen

Size of sieve used for screening: 0.5mm, 1mm

Formalin added to sample container: yes

Sample containers filled (number and type): 5 - 1 Liter

Comments/Notes GPS coordinates in logbook

labelled BR-32-Y10-R1 to R5 0-10 cm

Rep1 1000 Rep4 1030

Rep2 1005 Rep5 1035

Rep3 1025

BENTHIC RECOLONIZATION SAMPLE COLLECTION FORM

Sample Location Designation: BR-33　　Date of Collection: 7/14/16

Sample Collection Method: van veen　　Weather: Sunny ~70°

Field Personnel: see logbook

1. Was a Surface Sediment Sample Collection Form filled out for sediment samples collected for benthic organisms (*Record location coordinates, water depth, etc. on sediment collection form) ☐ Yes ☐ No — see logbook
2. Was the SPI survey performed at sample location? ☒ Yes ☐ No
3. Was a surface sediment sample collected for archival and potential chemical analysis? ☐ Yes ☒ No

Surficial Sediment Characteristics: (circle most descriptive) fine to medium

Texture: Smooth Fine Coarse | Clay Silt Sand Gravel Cobble

Color: Light Dark | Gray Brown Black Other: Rep 3 - little gravel, some silt - almost entirely shells in sample collected (Mussels and clam

Odor: Normal Petroleum Chemical H_2S None Other:

Presence of:

	Y/N	Percent	Description Type
Biological Structures:	Y		worms, casings, & small clam shells, large broken shells
Debris:	Y		leafy debris mussel shells
Oily Sheen:	N		barnacles, a few shrimp

Vertical Profile Characteristics:

	Description:
Changes in Sediment Characteristics:	almost completely silt Reps 4-2 / cm depositional Rep 5 layer but silt throughout as well lighter silt on top - RPD?
Presence & Depth of Redox Potential Discontinuity Layer:	Reps 1-2, 8-9cm depositional layer

Benthic Community Samples

Approximate quantity/volume of sediment from grab screen for benthos: 1/2 - 3/4 Van veen

Size of sieve used for screening: 0.5 mm, 1 mm

Formalin added to sample container: yes

Sample containers filled (number and type): 5 - 1 Liter

Comments/Notes: GPS coordinates in logbook
labelled BR-33-Y10-R1 to R5 0-10 cm
Rep 1 1050　Rep 4 1110
Rep 2 1100　Rep 5 1115
Rep 3 1105

ATTACHMENT D

Co-Located Sediment Grab Sample Collection Forms

SURFACE SEDIMENT SAMPLE COLLECTION FORM

Thea Foss and Wheeler-Osgood Waterways OMMP

Date: 7/12/16

Weather: sunny ~70°

Field Personnel: See logbook

Sample Type:

☒ 1. Performance Surface (0-10 cm)
☐ 2. Early Warning Recontamination (0-2 cm)
☐ 3. Performance Subsurface
☐ 4. Bioassay
☐ 5. Benthic Recolonization

Sample Designation BR-15-Y10-R1

Sample Method (Van Veen Surface Grab/Slope Composite)

Datum (Horizontal/Vertical) northing/easting

Sample Types 1, 2, 3, 4, 5:
*If sample type 4, were reference samples collected? ☐ Yes ☐ No

Leadline Water Depth 44.2' (A)
Predicted Tide Elevation 7.472 (B)
Mudline Elevation -36.73 (B-A)
Actual Tide Elevation

Run # or Composite Pt	Time	Latitude (Northing)	Longitude (Easting	Sample Criteria (Surface Grab Only) 1	2	3	4	5	Accept Sample Y/N	Comments (Include depth of sample)
1	1350	47°15'10.4	122°25'57.8	✓	✓	✓	✓	✓	Y	~13 cm total

Acceptance criteria: 1 Overlying water is present, 2 Water has low turbidity, 3 Sampler is not over filled, 4 Sample surface is flat, 5 Desired sample depth is reached

Sediment Sample Description

Sediment Sample Description (density, moisture, color, minor constituents, major constituents, other obs - *see field ref cards):
Smooth fine ~~sil~~ dark brown silt with slight/some fine sand ~1-2 cm light brown silt on surface

Sample containers filled (number and type):
1-500 ml, 1-1 liter

Laboratory analysis:
HOLD- PAHs, TOC, metals, Total solids, SVOCs, pesticides, PCBs

Thick Slope Cap Composite Sampling

Predicted tide elevation

Remediation area

Number of composite points

SURFACE SEDIMENT SAMPLE COLLECTION FORM

Thea Foss and Wheeler-Osgood Waterways OMMP

Date: 7/13/16

Weather: partly cloudy 265°

Field Personnel: see log book

Sample Type:

☒ 1. Performance Surface (0-10 cm)
☐ 2. Early Warning Recontamination (0-2 cm)
☐ 3. Performance Subsurface
☐ 4. Bioassay
☐ 5. Benthic Recolonization

Sample Designation BR-21-Y10-R1

Sample Method (Van Veen Surface Grab/Slope Composite)

Datum (Horizontal/Vertical) lat/long

Sample Types 1, 2, 3, 4, 5:
*If sample type 4, were reference samples collected? ☐ Yes ☐ No

Leadline Water Depth 39.4 (A)
Predicted Tide Elevation 3.24 (B)
Mudline Elevation -36.2 (B-A)
Actual Tide Elevation

Run # or Composite Pt	Time	Latitude (Northing)	Longitude (Easting	Sample Criteria (Surface Grab Only) 1	2	3	4	5	Accept Sample Y/N	Comments (Include depth of sample)
1	910	47°15'4.3	122°25'59.0	✓	✓	✓	✓	✓	Y	11.5 total

Acceptance criteria: 1 Overlying water is present, 2 Water has low turbidity, 3 Sampler is not over filled, 4 Sample surface is flat, 5 Desired sample depth is reached

Sediment Sample Description

Sediment Sample Description (density, moisture, color, minor constituents, major constituents, other obs - *see field ref cards):
smooth fine silt dark brown, w/ slight fine sand. no odor, ~2-3 mm RPD

Sample containers filled (number and type):
3 ~~[illegible]~~ - 1 Liter 3 - 500 ml

Laboratory analysis:
SVOCs, PAHs, metals, Total solids, total organic carbon, pesticides, PCBs
HOLD

Thick Slope Cap Composite Sampling

Predicted tide elevation

Remediation area

Number of composite points

SURFACE SEDIMENT SAMPLE COLLECTION FORM

Thea Foss and Wheeler-Osgood Waterways OMMP

Date: 7/13/16

Weather: cloudy ~65°

Field Personnel: see logbook

Sample Type:

- ☒ 1. Performance Surface (0-10 cm)
- ☐ 2. Early Warning Recontamination (0-2 cm)
- ☐ 3. Performance Subsurface
- ☐ 4. Bioassay
- ☐ 5. Benthic Recolonization

Sample Designation: BR-22-410-R1

Sample Method (~~Van Veen Surface~~ Grab/Slope Composite)

Datum (Horizontal/Vertical): lat/long

Sample Types 1, 2, 3, 4, 5:
*If sample type 4, were reference samples collected? ☐ Yes ☐ No

Leadline Water Depth: 36.2 (A)

Predicted Tide Elevation: 5.264 (B)

Mudline Elevation: -30.94 (B-A)

Actual Tide Elevation:

Run # or Composite Pt	Time	Latitude (Northing)	Longitude (Easting	Sample Criteria (Surface Grab Only) 1	2	3	4	5	Accept Sample Y/N	Comments (Include depth of sample)
~~B~~ 1	1040	47°15'0.2	122°25'56	✓	✓	✓	✓	✓	Y	~12 cm

Acceptance criteria: 1 Overlying water is present, 2 Water has low turbidity, 3 Sampler is not over filled, 4 Sample surface is flat, 5 Desired sample depth is reached

Sediment Sample Description

Sediment Sample Description (density, moisture, color, minor constituents, major constituents, other obs - *see field ref cards):
smooth fine dark brown silt, no odor, 0.5 cm RPD, slight/some fine sand

Sample containers filled (number and type):
1-32 oz

Laboratory analysis:
HOLD - PAHs, metals, TOC, total solids, SVOCs, pesticides, PCBs

Thick Slope Cap Composite Sampling

Predicted tide elevation:

Remediation area:

Number of composite points:

SURFACE SEDIMENT SAMPLE COLLECTION FORM

Thea Foss and Wheeler-Osgood Waterways OMMP

Date: 7/13/16

Weather: partly cloudy ~65°

Field Personnel: see logbook

Sample Type:

☒ 1. Performance Surface (0-10 cm)
☐ 2. Early Warning Recontamination (0-2 cm)
☐ 3. Performance Subsurface
☐ 4. Bioassay
☐ 5. Benthic Recolonization

Sample Designation BR-28-410-R1

Sample Method (Van Veen Surface Grab/Slope Composite)

Datum (Horizontal/Vertical) lat / long

Sample Types 1, 2, 3, 4, 5:
*If sample type 4, were reference samples collected? ☐ Yes ☐ No

Leadline Water Depth 28.7' (A)
Predicted Tide Elevation 7.892 (B)
Mudline Elevation -20.81 (B-A)
Actual Tide Elevation

Run # or Composite Pt	Time	Latitude (Northing)	Longitude (Easting	Sample Criteria (Surface Grab Only) 1	2	3	4	5	Accept Sample Y/N	Comments (Include depth of sample)
1	1435	47°14'49.1	122°25'53.5	✓	✓	✓	✓	✓	Y	~11 cm

Acceptance criteria: 1 Overlying water is present, 2 Water has low turbidity, 3 Sampler is not over filled, 4 Sample surface is flat, 5 Desired sample depth is reached

Sediment Sample Description

Sediment Sample Description (density, moisture, color, minor constituents, major constituents, other obs - *see field ref cards):
smooth fine ~~dark~~ med brown silt w/ some fine sand, no odor

Sample containers filled (number and type):
2-500 ml Duplicate collected BR-28-410-DUP 1440

Laboratory analysis:
HOLD - PAHs, metals, TOC, total solids, pesticides, PCBs, SVOCs

Thick Slope Cap Composite Sampling

Predicted tide elevation

Remediation area

Number of composite points